Key Performance Indicators Their Role And Evolution In Performance Specified Maintenance Contracts

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SYNOPSIS

Australia expends seven billion dollars annually on its 800,000 kilometres of roadways of which only 319,000 (40%) are paved with bituminous materials or concrete (around 2 Billion Square metres). With a population of 20 million people, this implies that every Australian spends around $350 per year to maintain the paved road network. Further that expenditure will maintain around 0.3m^2 of roadway (about the size of an average pothole) yet, at this time, there are no national performance criteria which will demonstrate the effectiveness of the road maintenance dollar, or compare the performance of road agencies across local or state jurisdictions. Road accident trauma is said to cost the nation $13 Billion annually.

The two hundred million dollar Sydney Performance Specified Maintenance Contract (PSMC) will complete its 10th year of operation in October 2005. The author has been associated with the contract from conception, including the bid process, start up and continuous operation since October 1995. The period 1993 to 1995 required the formulation of the bid, validation of input data and verification of many, many cost proposals.

The contract is based on the contractor meeting Key Performance Indicators (KPI)),Eevery year for ten years, . This requireding the consultant to predict the condition of the Network at start up and for ten years into the future and to determine the absolute costs, for the full ten years, necessary to meet those KPI for a ten-year lump sum contract.

This paper examines the changes that have occurred over the past ten years.

The paper discusses the innovation in the measurement and standarisation of KPIs, within the PSMC environment and their evolution into a Fitness For Purpose Indicator based on the analysis techniques of HDM4 and the 10 9 parameters for which there are validated deterioration models.

This Fitness For Purpose Indicator is demonstrated as a method for ranking roads as a function of the triple E bottom line - Engineering Feasibility, Economic Viability and Environmental Sustainability, and to be suitable for comparison between Networks at the same time as providing the framework for Engineering Analysis.

INTRODUCTION

The Roads and Traffic Authority's – Sydney Performance Specified Maintenance Contract covers approximately 35% of metropolitan Sydney's state owned road system. The network comprises flexible pavements (about 48%), rigid pavements and rigid pavements covered by thin bituminous mixtures. The network consists of 1888 lane km (6 Million square metres) of pavement, 190 bridges, 760 sets of traffic Control Signals (and growing), 100 hectares of median strips, gardens and verges. Forty five thousand raised pavement markers are replaced annually.

In this environment the Maintenance Contractor (Transfield Services) must determine both scheduled and responsive maintenance that will comply with Key Performance Indicators that were proposed within the bid and a Code of Maintenance Standards (COMS) that dictate items such as maximum length of grass, mean time between identification and rectification of Safety and Serviceability issues, such as response times for pot hole repair.

This paper will examine the original KPI proposals and their evolution over the past ten-years, leading to a postulation as to how such indicators can be codified for widespread national usage.

Proposed Key Performance Indicators

The original KPI were based on the critical parameters required to provide a safe, smooth riding, waterproof facility capable of carrying the applied loads, now and into the future.

Safety: Providing a safe environment for all users through the parameters of Skid Resistance (both coefficient of friction and macrotexture), elimination of potholes, edge breaks and rut depths sufficiently deep to initiate hydroplaning.

Serviceability: Roughness, total damaged area and total area of cracking.

Structural Adequacy: As measured by remaining life as a function of traffic, climate, materials and wide structural cracking. To this end the following KPI were proposed at that time.

An artificial road hierarchy was also proposed consisting of four types of road usage:

Class 1: Major arterials, with day time traffic so heavy that maintenance activities need be undertaken at night.

Class 2: Major arterials, for which maintenance could be undertaken by day or by night.

Class 3: Distributors and collectors

Class 4: Roads in National Parks – No conditions other than Roughness were applied to this class.

The following KPI were proposed with the tender;

Skid Resistance: Any removal of surfacing material must be replaced with the same quality or better skid resistance surfacing.

Structural Capacity: At the end of the contract no link (maintenance segment) would have less than 10 years remaining life.

Rutting: A sliding scale was proposed such that critical locationssuch ;as approaches to signals, pedestrian crossings etc would have rut depths less than that likely to initiate hydroplaning for the conditions, with a maximum mean rut depth of 15mm 10mm on all classes of roads.

Serviceability: At the end of the contract there will be no more than 10% of Class 1 and 2 roads with more than 10% fatigue cracking. This number was increased to 15%/15% for Class 3 roads.

At the end of the contract there would be no more than 10% of Class 1 and 2 roads with more than 10% of total damaged area. This value was increased to not more than 15% with more than 15% total damaged area for Class 3 roads.

Roughness: For this purpose the National Roughness Measurement was used where 30 NRM counts are roughly equal to 1 International Roughness Index (IRI) unit. Each year and at the end of the contract there is a target NRM which is no worse that the weighted mean (by lane link) for the entire network. This target, which is known as "the green worm" is the major focus for the contract, .in the early years It was also soon realised that every NRM point above the "green worm" would cost the maintenance contractor and additional 1 million dollars to rectify.

The Code of Maintenance Standards being generally a method for monitoring "responsive maintenance "will not be examined in this paper.

Innovation – Equipment

Almost from day one, it was realised that the equipment, on which, we had based our assumptions was not up to the task and required upgrading. Our detailed visual inspection procedures using a unit we called an Automated Road Evaluation Vehicle (AREV) provided visual condition rating and a video recording of both the observed distress and the Road Network Inspector's description.what had been observed and how the inspectors described it These were satisfactory and remain so today, albeit with improved cameras and recording methodologies.

We had 3 beam laser profilographs which could produce IRI measurements but were useless for evaluating rut depth- this necessitated commissioning a 13 beam laser profilograph which would enable better precision for the transverse profile.

Our Falling Weight Deflectometer (FWD) needed to operate at maximum load and maximum drop height in order to obtain any valid measurement of the deflection bowl for the generally very stiff road sections abundant within the network. This was rapidly destroying the FWD. It was therefore urgent to purchase a Heavy Weight Deflectometer, in order to be able to operate in the mid range of operating conditions, rather than at extreme range. Skid Resistance testing looked to be a major problem .We had pioneered a extremely useful device known as The Yandell-Mee Texture Friction Device, it had been proven to be very successful for predicting the two components of skid resistance, but was neither widely understood nor validated by others than ourselves. We needed a device that had international recognition and was sufficiently mobile to undertake minor project level jobs quickly. We were assisted in this respect by the outcomes of the ASTM/PIARC Skid Resistance harmonization experiments and the evolution of The International Friction Index (IFI). This resulted in the purchase of the Norsemeter ROAR to service this need. Clearly the early stages of the contract required a major review of the methodology, but we were committed to the outcomes therefore further research needed undertaking to devise methods to comply with the intent of the KPI.

Project Specific Methods

Two approaches to network analysis need to be considered, those that impact on the outcomes at the Project (or candidate section) level, where individual candidate sections must be evaluated to determine the best whole of life outcome for that section and those that impact on the Network as a whole (network level). The nNetwork outcomes, as a whole, from today to the end of the contract and beyond must become part of The Operational Works Programme.

It must be remembered that any Any changes to the methods used must be capable ofapart from producing the annual forward works programme that must not only meet the KPI for the network at the yearly anniversary of contract, but also demonstrate that the end of contract conditions will be met with no increase in costs. This requires required both lateral thought and intellectual calisthenics.

Visual Inspection methodologies have remained reasonably consistent throughout the contract except that the evolution of deterioration models for environmental cracking through the International Study of Highway Design and Maintenance (ISOHDM) required the addition of this that attribute. Cameras, computers and safety issues have changed but all for the better. The integration of visual inspection and profile measurements is now a reality and combines improved Occupational Heath and Safety concerns with improved productivity.

Roughness Measurements have also remained constant; again improved computing power has enabled both measurement and analysis to be undertaken at much smaller intervals with consequential improvements in both prediction and identification of potential problems. This enables early intervention for maintenance and hence reduced costs. The maintenance need is frequently preventive, rather than corrective or rehabilitation.

Major changes have, however, occurred in the measurement, analysis and interpretation of safety and structural issues, at the project level. and Network level

Rut Depth Measurements – Technology with respect to this parameter has moved quickly. The original 13 beam profilometer was obsolete within 4 years and precision demanded that a device capable of measuring rut depth at intervals of no more than 10mm and capable of computing rut depths by a plethora of methods, 3 m string line, 1.2m straight edge and 2m straight edge being the predominate methods, in addition to a variety of bins sizes for measurement of outcomes. We still have the requirement that we must eliminate potential hydroplaning, throughout the network. A method was devised for determination of critical conditions for hydroplaning requiring many facilities integrated within the new age device, including road geometry and texture.

Rut Depth Evaluation now is based on four methods of evaluation. Level 1 is only used for ranking and relies on the rut depth in the wheel path using straight edge concept. Level 2 is used for selection and allocation of candidate sections. Rut depth is computed for each lane link at 25m intervals and the so-called characteristic value computed for the lane link.

The characteristic value is based on the same description assigned to the structural parameters of deflection and curvature described in chapter 10 of "Pavement Design – A guide to the structural design of road pavements", Austroads 1992.
Where:

Characteristic Rut Depth = Average (μ) + f (Standard Deviation) (s).

and f is a function of the road type; for example: (Table 1)

Table 1 Values of "f" for determination of characteristic values

ROAD CLASS	F	% OF ALL VALUES THAT WILL BE COVERED BY THE CHARACTERISTIC VALUE
ARTERIALS	2.00	97.5
COLLECTORS AND DISTRIBUTORS	1.65	95.0
LOCAL ACCESS & RESIDENTIAL	1.30	90

Where the "characteristic rut depth" for a lane link exceeds 20mm the section is scheduled for a Level 3 investigation (required for prioritisation and programming).

Level 3 Investigation requires reprocessing the raw data from the profilograph at 1m intervals and a detailed review of the rut depth profile site including detailed visual inspection of any anomalies. This methodology has been found useful for the determination of the KPMKPI.

In the following example a section of road with a characteristic rut depth of 60mm, was reprocessed at 1m intervals and graphed. From the graph (Figure 1) it was clearly established that the high characteristic value was the result of a short section of pavement with a deep depression, . which should have been identified by normal network inspection.

A second section with characteristic rut depth of 33mm was processed similarly and found to be generally of a rut depth that would engender hydroplaning (Figure 2). This section was scheduled for Level 4 investigation, by examining hydroplaning potential. For this purpose road geometry is required to establish drainage paths of the pavement, macrotexture to establish drainage paths between aggregate particles, and rainfall intensity values to establish potential puddle depth. Using the log normal distribution statistics for the input parameters a Monte Carlo analysis is undertaken to determine the probability density curve for aquaplaning under the site conditions. This allows the pavement engineer to examine the risk for the site and advance (or retard) rehabilitation of the site within the operational works programme.

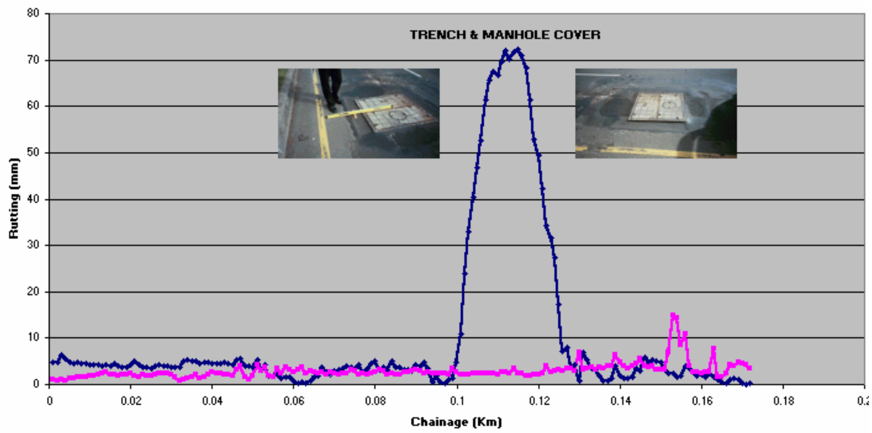

Figure 1 – Rut Depth Profile at 1m intervals for highest characteristic rut depth

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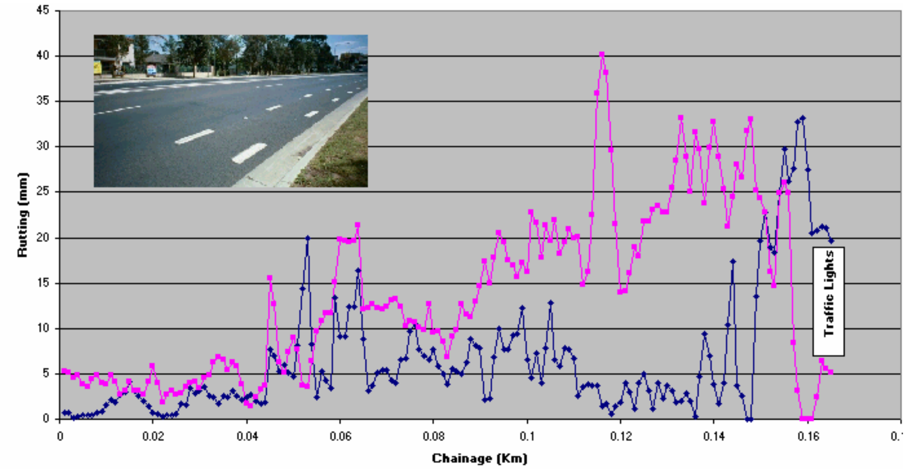

Figure 2 - Rut Depth Profile of potential hydroplaning site

Like hydroplaning Skid Resistance has become a pressing issue in relation to the inherent requirement to be able to demonstrate a duty of care in road maintenance management. The IFI has provided a pathway for determination of two risk profiles – Loss of Control and Stopping Distance Analysis.

Using similar analysis techniques to the rut depth and hydroplaning potential, the characteristic F_{60} (coefficient of friction at 60kph) and Vp (slip speed) are computed for the subject section. It should be noted that the IFI does not mean that large amounts of data obtained by the SCRIM device and sand patch methods are discarded, they are merely carried forward to convert to the IFI format. This is the Level 2 analysis to provide selection and allocation of candidate sections. Where either F_{60} of Sp Vp fail predefined intervention levels as a function of site category or speed profile, the candidate section is scheduled for Level 3 investigation. This method requires processing data at closer intervals and graphing to identify sub sections, which may give rise to local anomalies. Level 4 analyses using the Monte Carlo analysis technique defines the probability density curve, enabling computation of the risk of either stopping or loss of control for the subject site. Clearly candidate sections can be elevated or downgraded within the operational works programme as a function of this information.

Structural Adequacy – The reader will recall that one of the KPI, proposed at bid, was that at the end of the contract, no link would have less than 10 years remaining life. Candidate sections identified by the pavement management analysis (Road Manager) in any one year are tested at 20m intervals for full deflection bowl (9 deflectors), back analysed, using ELMOD4 to provide both subgrade CBR and characteristic deflection and curvature. Using the methodology of Chapter 10 of the Austroads guide. Characteristic Deflection and curvature are used to compute a quantity we have called “Structural Deficit” (SD) that is the thickness of AC overlay necessary to rehabilitate the test point to meet twenty-year design traffic intensity for the climatic conditions of the site. This data is graphed along the section length and candidate treatments established according to the broad groupings SD < 40mm – No action, SD 40 to 70mm – Mill and Replace. More than 70mm – rehabilitation Rehabilitation (Sites scheduled for Mill and Replace or Rehabilitation, are designed using a full mechanistic design methodology incorporating climate (seasonally adjusted), detailed axle loads, and appropriate materials properties, for a 40 year design traffic intensity. Following construction the rehabilitated section is again tested for full deflection bowl and evaluated mechanistically (we now know all layer thickness) to confirm that the design parameters have been met. The implication here is that if the section rehabilitated now has a residual life (in terms of esa, at this time) greater than the time to the end of the contract + 10 years and the remainder of the section potentially only requires a thin AC overlay in order to comply with the residual life requirement., then the section is structurally sound.

Final approval is determined by testing the complete link (all lanes) at 50m intervals and computing the Structural Deficit for each point. The link is rejected as conforming if more than 2.5% of all results exceed 60mm structural deficit or 7.5% exceed a 30mm structural deficit.

Network Analysis

Network owners need to be able to test the condition of sub networks against not only Key Performance Indicators but across boundaries, for example a State Road Authority must be able to compare Local Government A with Local Governments B&C in order to allocate funding equitably. Legislators and senior administrators have neither the time nor the inclination to study graphs charts and tables, for a multiplicity of parameters. A single number is required that not only will differentiates between jurisdictions, sections, contractors etc but is based on sufficient input parameters to enable the evaluation of engineering standards in addition toas well as economic and sustainability comparisons. We have called this the Fitness For Purpose Indicator (F^2PI).

The Fitness For Purpose Indicator has evolved from experience with the PSMC. Nationwide there is a need to be able to differentiate between roads that appear the same but have different maintenance requirements. F^2PI Allow enables administrators to calculate, with reliability, the strategic maintenance costs as a function of current condition and allow a comparison of road user costs and environmental impact as a function of both pavement condition and maintenance activities.

Maintenance Standards

No two-road authorities desire to have the same road condition standards; in many cases different funding strategies also dictate the type of maintenance. It is also important to have different levels of maintenance for different road hierarchy. Four standards of fitness are proposed.

Gold Standard: The very highest standard of road maintenance that a road authority can achieve, consistent with a high speedhigh-speed motorway between two major cities. Vehicles can be expected to cruise comfortably at high speed.

Silver Standard: This standard is about 10% less rigorous than the Gold Standard and is applicable for high volume arterial roads between major centres.

Bronze Standard: Again about 10% less rigorous than the silver standard and consistent with local roads distributing traffic to factories and homes.

Base Standard: Is the minimum level of maintenance that can be tolerated. Base standard generally involves sealing cracks, patching damaged areas and reconstruction when the pavement becomes unserviceable.

Pavement Parameters

Pavement parameters are chosen according to the three key criteria of a PSMC namely Safety, Serviceability and Structural Adequacy. Another consideration, when choosing these parameters is the necessity to have reliable deterioration models, in order to predict future performance of the network under differing maintenance regimes. ISOHDM developments have provided these models together with the means of calibrating them to localised conditions. Nine parameters to reflect the pavement condition and to model future behavior have been chosen from that source as being suitable.

Safety: Parameters are Potholes, Rutting, Edge Break, Skid Resistance (SCRIM - SFC50, and Mean Profile Depth) jointly to provide the International Friction Index (IFI). Table 2 outlines Safety maintenance for each of the four standards.

Table 2 – Safety Maintenance Standards

PARAMETER	DESCRIPTION	CRITERION	BASE	BRONZE	SILVER	GOLD
POTHOLES [1]	Number per kilometre – see HDM4 definition	NO MORE THAN	15	10	5	2
RUT DEPTH	Maximum Deviation (mm) under a 2m Straight Edge (mm)	95 % LESS THAN	25	20	10	5
EDGE BREAK	Square Metres per km	NOT MORE THAN	40	20	10	5
SKID RESISTANCE	International Friction Index	95% (SFC_{50}) GREATER THAN	0.40	0.45	0.50	0.55
		95% Mean Profile Depth (mm) (MPD) GREATER THAN	0.6	0.8	1.0	1.2

Note [1] A pothole is defined as a volume of $0.01m^3$ that is 330mm square by 100mm deep or a summation of smaller potholes to this volume.

Serviceability: Roughness, Total Damaged Area (includes irregular patches as *prima facie* evidence of prior failure, Total area of cracked carriageway. Table 3 Serviceability Maintenance provides examples for four standards of service.

Table 3 – Serviceability Maintenance Standards

PARAMETER	DESCRIPTION	CRITERION	BASE	BRONZE	SILVER	GOLD
ROUGHNESS	International Roughness Index (IRI)	95% LESS THAN	5.3	4.2	3.4	2.7
TOTAL AREA OF DAMAGED PAVEMENT	Percentage of Section Area see HDM4 Definition for ADAMS – Note includes irregular patches	95 % LESS THAN	50	40	30	20
TOTAL AREA OF CRACKED CARRAIGEWAY	Percentage of section Area – see HDM4 Definition	95% LESS THAN	30	20	10	5

Note: The 95^{th} Percentile is the characteristic value described above. At 1.65 standard deviations

Structural Adequacy: Will the pavement carry the loads to be applied, now and in the future? Parameters include the Area of Wide Structural Cracking (fatigue) and Structural Deficiency. Examples of the structural adequacy standards are shown in Table 4.

Table 4 – Structural Adequacy

PARAMETER	DESCRIPTION	CRITERION	BASE	BRONZE	SILVER	GOLD
WIDE STRUCTURAL CRACKING	Percentage of section Area – see HDM4 Definition	95% LESS THAN	8	6	4	2
STRUCTURAL DEFICIENCY	THICKNESS OF ASPHALTIC CONCRETE NECESSARY TO MEET 20 YEAR DESIGN TRAFFIC INTENSITY	mm of Asphaltic Concrete 95% less than	75	50	25	0

Note: Structural Deficiency is defined as the thickness of Asphaltic Concrete required to meet the Analysis Period – Design Traffic.

With the exception of Structural Deficiency all the above are input parameters to the World Road association's Association's Highway Design and Management analysis tool – HDM4. The Structural Number, which is vital to the computation of pavement condition as a function of time and traffic can be computed directly from deflection used in the calculation of Structural Deficit. This Structural Deficit is, therefore, a surrogate parameter for Structural Number.

Total Damaged Area *per se* is not directly a HDM4 parameter. It is computed as the sum of cracking + ravelling + potholes. In the context of the Fitness For Purpose Indicator irregular patches are included as potholes.

Computation Of F^2PI

Experience suggests that 70% of maintenance costs for a road network, in a Urban environment are related to maintenance of the traveled way, with 30% allocated to non pavement items such as drains, signs, lines, litter and vegetation control. Therefore 70 points are allocated to the computation of F^2PI, with 7 points allocated to those parameters that are gold standard, 6 points to silver standard, 5 points to bronze standard and 4 points to base standard. Parameters that are below base standard are valued at 0 (zero) points. Where parameters are not collected or available they are valued the same as base condition that is 4 points. F^2PI can be computed for a section a road, a district or a network. Typical maintenance "scores " are given in Table 5

Table 5 – Maintenance Standard Assignment Scores

STANDARD	ASSIGNMENT	RANGE
GOLD	7	60 -70
SILVER	6	50 – 60
BRONZE	5	40-50
BASIC MAINTENANCE	4	<40

Case Study F^2PI By Road Hierarchy

Using the above classification and methodology, the F^2PI methodology was tested for a rural network by road hierarchy to evaluate the relative score for each type of road in the network and for the overall network. Table 6 provides the outcome of the analysis. The length of that road section and the F^2PI for that section weighted for each road in a class.

Table 6 - Case Study F^2PI by Road Class

ROAD HIERARCHY	WEIGHTED F2PI	TOTAL LENGTH (KM)	MAINTENANCE STANDARD
2ARTERIAL	51.9	98.1	Silver
3COLLECTOR/DISTRIBUTOR	53.7	513.6	Silver
7LOCAL ACCESS	48.3	94.8	Bronze
OverallNETWORK	52.7	724.1706.5	Silver

F^2PI To Compute Total Transportation Costs

The ten road condition parameters have beenwere chosen because they are input parameters to HDM4 As such they can be used to compute Total Transportation Costs, comprising:

Maintenance, (Timing and Costs), Vehicle Operating Costs, Travel Time Costs, Accident Costs, and Vehicular Emissions can be determined by any of the analytical tools of HDM4 – Strategy, Programme or Project Analysis.

Maintenance Standards have been prepared for each of the road surface types, such that the maintenance standard will produce a network, district or section to meet the Gold, Silver, Bronze or Base Standard. Table 7 is an example of the Gold Maintenance Standard, applicable to Australia and New Zealand. This that will produce road conditions consistently at the gold standard throughout the analysis period.

Table 8 is typical of the maintenance standard that will maintain a flexible pavement at the basic standard.

Table 5 7 Gold Maintenance Standard – Flexible Pavements

Rank	SCENARIO	General		Design			INTERVENTION									Limitations		Cost
		Surface	Intervention Type	Description	SNP	Strength Coefft	Roughness	Severely Damaged Area	Rut Depth Std Dev	Rut Depth Mean	TEXTURE	Total Cracking	Edge Break (m^2/k)	Potholes (No /km)	Wide Structural Cracking	Min return period	AADT	Per Sq. m
1	REPLACEMENT	Bituminous	Responsive	Seal on Granular Pavement	4.5		>3.4	>8%									0 to 7500	$95.00
2	DEEP STRENGTH AC	Bituminous	Responsive	Asphalt Mix on Asphalt Base	4.5		>3.4	>8%									>7500	$95.00
3	MILL & RESHEET - Due to Rutting	Bituminous	Responsive	40mm AC		0.2			>5mm								all	$18.00
4	MILL & RESHEET - Due to Cracking	Bituminous	Responsive	40mm AC		0.2						>20%					all	$18.00
5	MILL & RESHEET - Due to Damage	Bituminous	Responsive	40mm AC		0.2		>20%									all	$18.00
6	MILL & RESHEET - Due to Roughness	Bituminous	Responsive	40mm AC		0.2	>2.8										all	$18.00
7	75mm AC OVERLAY	Bituminous	Responsive	75mm AC		0.4	>2.7	>10%										$18.00
8	50mm AC Overlay	Bituminous	Responsive	50mm AC		0.3	>2.7	>6%								12 years	>7500	$13.00
9	INLAY 30% of P'MENT	Bituminous	Responsive	40mm AC		0.2				>12mm								$29.00
10	HEAVY PATCHING- 35% of P'MENT	Bituminous	Responsive	Full Depth AC				>10% and <40%										$27.00
##	AREA PATCHING to 10% of P'MENT	Bituminous	Responsive	Full Depth AC				>6% and <25%										$25.00
12	2 COAT SHAPE CORRECTION	Surface Dressing	Responsive	2 coat seal-25mm thick		0.25	>2.7										<7500	$25.00
13	2 COAT STRENGTHENING	Surface Dressing	Responsive	2 coat seal-25mm thick		0.35		>5%										$35.00
14	RESEAL	Surface Dressing	Responsive	15mm S.Seal		0.2						>5%				10 years	<7500	$3.50
15	TEXTURING	Surface Dressing	Responsive	15mm S.Seal		0.2					<1.8					3 Years	<7500	$3.50
16	EDGE REPAIR	Bituminous	Scheduled	Patching									10				<10,000	$42.00
17	POTHOLE REPAIR	Bituminous	Responsive	Patching										2			< 10000	$50.00
18	CRACK SEALING	Bituminous	Responsive	Crack Sealing											>2%		<7500	$7.00

Table 6 8 – Basic Maintenance Standard, Flexible Pavements

RANK	SCENARIO	GENERAL		DESIGN				INTERVENTION					LIMITATIONS		COST
		Surface	Intervention Type	Description	SNP	Strength Coefft	Frequency (Years)	Roughness	Severely Damaged Area	Edge Break (m2/km)	Potholes (No. km)	Wide Structural Cracking	Min. Return Period	AADT	Per Sq. m
1	REPLACEMENT	Bituminous	Responsive	Seal on Granular Pavement	3			>6.5	>25%					< 7500	$85.00
2	DEEP STRENGTH AC	Bituminous	Responsive	Asphalt Mix on Asphalt Base	3			>6.5	>25%					>7500	$85.00
3	MILL & RESHEET	Bituminous	Responsive	40mm AC		0.2	10		>50					>7500	$18.00
4	30mm AC Overlay	Bituminous	Scheduled	30mm AC		0.2							10 years	>7500	$13.00
5	AREA PATCHING	Bituminous	Responsive	Full Depth AC					>30					all	$25.00
6	RESEAL	Bituminous	Scheduled	15mm S.Seal		0.2	7						7 years	<7500	$3.50
7	EDGE REPAIR	Bituminous	Scheduled	Patching						50				<10,000	$42.00
8	POTHOLE REPAIR	Bituminous	Responsive	Patching							25			< 10,000	$50.00
9	CRACK SEALING	Bituminous	Responsive	Crack Sealing								>20%		<7500	$7.00

Using F²PI To Compute Life Cycle Maintenance Costs

For this example three road types, with similar F²Pifrom the case study (Table 6) were tested Hierarchies 2,3 and 4 of Table 6) for whole of life costs and four vehicle configurations – a medium car, a medium Rigid rigid Trucktruck, a 6 axle truck and a fleet made up by a combination of all four, as follows, (Table 89).

Table 8 9 – Distribution of Vehicles in Fleet

VEHICLE	PERCENT COMPOSITION		
	MEDIUM CAR	MEDIUM TRUCK	6 AXLE TRUCK
Arterial Road	86%	10%	4%
Distributor/Collector Road	95%	4%	1%
Local Access	98%	1.8%	0.2%
Network	90%	8%	2.0%

HDM4 Strategy Analysis was used for analysis, over a 25-year analysis period at 7% discount factor. The objective was to minimise cost for a target IRI of 2.8. In each case the F²PI for the road was classified as Silver, Arterial (52), Silver - Distributor/Collector (5254) and Bronze Local Access (5148). Theirregular weighted average for the network was 53.

The following comparison of maintenance costs per square metre per year were obtained, (Table 10);

Table 9 10– Comparison of Maintenance Costs by Vehicle Type, Road Type and Maintenance Standard ($ per square metre per year)

VEHICLE	ROAD TYPE	AADT	MAINTENANCE STANDARD			
			Basic	Bronze	Silver	Gold
MEDIUM CAR	Arterial	5000	1.84	2.83	4.43	3.79
	Collector/Distributor	1500	1.59	2.27	3.65	3.65
	Local Access	100	1.47	2.24	3.61	3.64
MEDIUM TRUCK	Arterial	5000	2.18	4.13	5.30	4.25
	Collector/Distributor	1500	1.60	3.11	4.82	4.10
	Local Access	100	1.49	2.52	3.91	3.82
6 AXLE TRUCK	Arterial	5000	4.56	8.77	11.48	6.64
	Collector/Distributor	1500	1.69	5.35	6.28	4.63
	Local Access	100	1.52	2.66	5.52	4.09
FLEET	Arterial	5000	2.06	3.15	5.03	4.02
	Collector/Distributor	1500	1.54	2.91	3.76	3.86
	Local Access	100	1.52	2.66	4.52	4.09
	Network	1000	1.54	1.75	2.08	2.53

Note 1: Apparent anomalies between Gold and Silver standards are frequently attributed to the difference in structural number and hence rate of deterioration, given that deterioration models have a high sensitivity to structural capacity.

Note 2: The existing condition of roads is at Silver and Bronze Standard; therefore maintaining these roads at a lower standard will generally produce lower overall maintenance costs.

Using F²PI To Compute Vehicle Operating Costs

Using the same pavement condition data and maintenance standards as above, HDM4 Strategy analysis was used to compute Vehicle operating Operating Costs on the basis of travel distances expected by an Australian fleet that is;

Medium Car: 23,000 km per year
Medium Truck: 45,000 per year
6 Axle Truck: 83,000 per year

This provides an the Vehicle Operating Cost per kilometre and the fleet for each road type, Table 11..

Table 10 11 – Comparison of Vehicle Operating Costs by Vehicle Type, Road Type and Maintenance Standard ($ per kilometre)

VEHICLE	ROAD TYPE	AADT	MAINTENANCE STANDARD			
			BASIC	BRONZE	SILVER	GOLD
MEDIUM CAR	Arterial	5000	0.19	0.19	0.19	0.18
	Collector/Distributor	1500	0.20	0.19	0.19	0.19
	Local Access	100	0.21	0.19	0.20	0.20
MEDIUM TRUCK	Arterial	5000	0.57	0.54	0.54	0.54
	Collector/Distributor	1500	0.63	0.61	0.60	0.60
	Local Access	100	0.70	0.67	0.67	0.67
6 AXLE TRUCK	Arterial	5000	1.34	1.09	1.01	0.97
	Collector/Distributor	1500	1.17	1.05	1.03	1.03
	Local Access	100	1.24	1.14	1.13	1.13
FLEET	Arterial	5000	0.39	0.34	0.34	0.34
	Collector/Distributor	1500	0.27	0.26	0.26	0.26
	Local Access	100	0.22	0.21	0.21	0.21
	Network	1000	0.62	0.58	0.55	0.47

Note: As to be expected the apparent differences appear small for other than a 6 axle truck, however given that this type of vehicle plies 83,000 km per year, the implication is that the difference in operating costs between an arterial road at Gold standard and one at basic Basic standard of 37 cents per km accrues to $37,000 over a year – a not insignificant amount.

Using F^{2}PI To Compute Vehicle Emissions

It is an important function of the roading engineer to consider sustainability issues, when making judgment as to maintenance scenarios. HDM4 provides tools for this purpose and they have been computed for this study in order to demonstrate the overall usefulness of the F^{2}PI tool. The results derived from this study are a factor of 100+ less than those espoused by politicians as they speak of reduction in power house emissions being equivalent to taking large numbers of cars off Sydney's roads. The writer has no real feel for the quantum of the values obtained. They are reproduced , in Table 12, primarily as an example of the use, and should not be taken at this time as being representative of actual values.

Table 11 12– Comparison of Vehicle Emissions by Vehicle Type and Maintenance Standard (Kg of Hydrocarbons per kilometre)

VEHICLE	ROAD TYPE	AADT	MAINTENANCE STANDARD			
			BASIC	BRONZE	SILVER	GOLD
MEDIUM CAR	Network	5000	1.04	0.86	0.84	0.75
MEDIUM TRUCK (PETROL)	Network	5000	1.21	1.04	1.00	.86
6 AXLE TRUCK	Network	5000	0.27	0.26	0.26	0.25
FLEET	Network	5000	0.89	0.71	0.66	0.64

Using F^{2}PI To Evaluate Alternate Maintenance Scenarios

The case study outlined above demonstrates the capability that the same data used for the determination of a Fitness For Purpose Indicator enables comparison of condition between road hierarchies. The same approach can be used by the pavement engineer to evaluate alternate strategies for a network as a function of road maintenance costs, road user costs and vehicular emissions. The analysis using the above data over a 25-year analysis period at a 7% discount factor yields the outcomes of Table 13

Table 14 13 - Outcomes For Case Study Network

MAINTENANCE STANDARD	ROAD MAINTENANCE COST ($/M2)	ROAD USER COST ($/KM)	HYDROCARBON EMISSIONS (KG/KM)
GOLD	2.53	0.47	0.64
SILVER	2.08	0.55	0.66
BRONZE	1.75	0.58	0.71
BASE	1.54	0.62	0.89

Given that the overall condition of the network is SILVER, based on these results the road authority can chose to maintain their current network, or choose to allow the network to deteriorate which will cost less money but have increased road user costs and emissions. They may even choose to upgrade the condition of the network to gold GOLD at significant cost, but capitalise the savings to both the road user and the environment.

Reduction In Road Accident Trauma

HDM4 provides a facility to evaluate reduction in the cost of accidents as the result of different maintenance strategies. Whilst this writer has not yet evaluated this effect, the methodology can be utilised to examine the potential reduction in road trauma costs due to improved maintenance standards. It could then represent the fourth criterion in Table 13 (above).

CONCLUSIONS

The advent of a ten year, 200 million dollar contract to maintain the major roads on 35% of the Sydney Region, by private contractor, required a new approach to the practice of road maintenance. The contractor not only had to predict the condition of a number of parameters each year of the ten years, but provide a lump sum price for provision of all maintenance within the road reserve. There would be no retreat from either costs or Key Performance Indicators.

During the preparation, two years, and the last eight years of operation, changes to condition monitoring methods, computing power and attitudes to safety and duty of care issues forced a rethink of the original proposals and how they must now happen. At the same time as this evolution, the original KPI and cost must remain unchanged.

Engineering practices, are shown to reduce costs simply by “doing it smarter” at the Project Level. New approaches have allowed not only earlier intervention but also less costly alternatives. There remains, however a need to evaluate the network as a whole to establish whether any improvement or deterioration has occurred, as the conclusion of the contract approaches.

The World Road Association’s analysis package HDM4 provides a tool for comparison of conditions between networks, sections of road, road types or jurisdictions and to provide the facility to evaluate maintenance cost, vehicle operating cost, vehicular emissions and accident costs at the Strategy, Programme and Project Level. However it is opined that most Legislators, Treasurers and Administrators require a single number representing road condition to distribute funds equitably over jurisdictions.

A Fitness For Purpose Indicator based on the 9 pavement condition parameters for HDM4 is postulated, since they all have deterioration models and therefore provide a methodology to evaluate the road or network over a life cycle.

Using the analytical tools of HDM4 and the Fitness For Purpose parameters it has been shown that that it is possible to compare maintenance standards against outcomes for maintenance costs, vehicle operating costs, emissions and potentially accident costs. This permits treasury the opportunity to evaluate the consequences of higher or lower standards of maintenance on road users and environment.

BIOGRAPHY OF DR JOHN YEAMAN, FTSE, CPENG

John Yeaman is currently chairman of Pavement Management Services, a company he founded in 1980 to provide all the components necessary for a pavement management system. This included data collection, data base management and maintenance engineering. Between 1956 and 1974 he worked for a quarry company running a materials testing laboratory providing services to the crushed rock, bituminous, brick and concrete industries. During this period he studied part-time for a Master of Engineering Degree at the University of New South Wales, his research subject being Skid Resistance.

Between 1974 and 1980 he was technical director to SAMI Pty Ltd and involved in the development and implementation of road maintenance products, particularly the polymer modified bituminous products. During this time he completed his Ph.D studies at the University of New South Wales in the development of a pavement management system for local government.

In 1980 he founded Pavement Management Services to link the products of his studies to provide services to Local Government within Australia.

Many years ago Professor Monismith of the University of California stated publicly that John Yeaman's great contribution lies in his ability to take an item of research and convert it into application to benefit the community

During the past 23 years this has been the spring board for his motivation. Technology introduced into Australia and New Zealand during that period includes Falling Weight Deflection Testing – 1983, Yandell-Mee Texture Friction Device – 1986, Automated Road Evaluation Vehicle including Video Recording with voiced activated computers, Laser Profilometers for the measurement of Roughness and Rut Depth – 1984 and more recently for the measurement of Texture Depth – 2003. Equipment to measure the International Friction Index was introduced in 1996.

John Yeaman is actively involved in mentoring and encouraging young engineers to further their studies and is involved with the Institution of Engineers Accreditation Board for Engineering Institutions.

In November 2003 he was elected as a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE).