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HOLISTIC PAVEMENT MANAGEMENT - EXPERIENCES WITH PERFORMANCE BASED PAVEMENT MANAGEMENT IN AUSTRALIA AND SOUTH AFRICA

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Abstract

The first Pavement Management Systems (PMSs) were developed in the 1980's when the personal computer was in its infancy; mainframe computers were expensive and clumsy to work with. Engineers challenged the performance of hardware and software with the development of more powerful pavement management systems. This ensured that engineers continued to provide human input into the management of road networks. Through the 1990s, data collection was changing. Engineers continued to provide human input into the data collection process and especially into the application of identified needs. At the start of the 21st century, hardware, software and data collection equipment had progressed to the point where data collection, processing and performance modelling are well catered by various computer systems. Road management is being fully codified by outcomes based performance standards. Good data is collected, easily processed through complex models and good cost-effective maintenance and rehabilitation actions are computer generated to meet those performance standards – or so we think. Based on experience gained from the management of various road networks in Australia and South Africa over the last ten years, this paper describes the lessons learnt from utilizing PMSs in determining maintenance and rehabilitation requirements to meet performance standards. The limitations of performance standards are apparent, as is the essential need to ensure experienced engineers evaluate results from computer systems not only on paper but also in the field.

1. BACKGROUND

Historically road networks were managed on paper based systems developed by the personnel responsible within the road authority. These personnel had typically years of experience within the road authority and a good knowledge of the network. They also had good knowledge of the typical performance of the various classes of road within the network, the effect of the environment across the network, and the effect or success of applying the various rehabilitation and maintenance measures. The experience of the road authorities' personnel played an enormous role in the success of the management of the asset.

In the 1980's when mainframe computers were available, the more formalized pavement management processes flourished. However, mainframe computers were expensive and most often clumsy to work with, with difficult programming languages and limited abilities. Engineers challenged the software and performance of the computers. Even as the development of the personal computer and software developed at a fast rate, engineers and pavement managers through the 1980's and 1990's were always waiting for the next advance in the computer and software development. Now hardware and software have progressed to a point where data storage and retrieval, data processing and performance modelling are

well catered for at affordable costs. Complex models have been developed which best simulate the performance of each road within the network, and predict future performances.
Excellent optimization processes identify the most beneficial rehabilitation and maintenance treatments. Hence, pavement management systems now provide us with all the answers we need to manage the network – or so we think ?.

Experience has been gained in pavement management on performance based contracts both in Australia and South Africa. Lessons have been learnt in the complete pavement management processes and systems. The value of experienced engineers evaluating the PMS results and verifying them in the field has proved invaluable. Each contract has its own nuances, and the experiences from contracts in Australia and South Africa are discussed separately to highlight their nuances, and then are distilled to give a holistic look at the way forward for performance contracts.

2. DEVELOPMENT OF PERFORMANCE BASED CONTRACTS

Changing role of road authorities

During the past 15 years or so, road authorities around the world have followed an evolutionary path in gradually shifting the risk of road management over to its supplier. The traditional road authority was a provider of services, including design, construction and maintenance, with expertise in carrying out these functions. The new model used by some road authorities is that they are becoming asset managers and the purchasers of services. The levels of ‘traditional’ technical skills required in the design, construction and maintenance of road networks has been replaced in the new model with expertise in asset management and procurement of the outcomes desired by their customers. In the new model, the road authority role evolves from that of expert supplier to ‘informed purchaser’. The role differs between road authorities. In Australia, for example, the road authorities of South Australia, New South Wales, Victoria and Queensland continue to be providers of services. The road authorities of Western Australia and Tasmania evolved to being a purchaser of services.

In South Africa short-term performance based contracts which guaranteed performance of the product (Product Performance Guarantee Systems) were short lived. However full-scale risk transfer with pavement performance contracts over long-term periods were implemented in the 1990’s. These were typically in the form of Public Private Partnership contracts comprising the finance, design, construct, maintain and operate principle.

Evolution of maintenance contracts

The procurement of road maintenance has evolved as a result of the changing role. Many road authorities have adopted forms of performance contracts and specifications for maintenance to the extent that performance contracts or specifications have been used in some form by road authorities in most parts of the developed world.

Performance based maintenance contracts

The key elements of a performance contract are:

- A definition of the performance required (as opposed to the definition of the method to be used or simply the end product at the completion of construction)
- A requirement that a defined performance shall prevail over a suitable period of time.

Various terms are used by different authorities for these performance contracts, which in this paper are referred to generically as performance contracts:

- Performance Specified Maintenance Contract (PSMC)
- Outcomes based contract.

- Term Network Contract.
- Toll Concession contract.

One aspect of the definition of a performance contract is the inclusion of a time element. Many "performance" contracts endeavour to measure performance using measures which predict the expected performance, i.e. measurements taken at the end of a maintenance period are used to infer the expected life of the product. An example are the performance based resurfacing contracts being used by VicRoads and Transit New Zealand which use measures such as texture depth at the end of a maintenance period to predict the life of the new surface. The time period is generally 5-10 years. The rationale behind the long duration is to create an economic framework, which enables and encourages the contractor to meet long-term performance objectives (Austroads, 2003).

Risk in performance contracts

Performance contracts transfer risks to the contractor that have been traditionally been held by the road authority. The risk issue is managed by the contractor through modelling the future road network condition and providing for the works needed to meet the contracted performance. In this regard the most significant contractor's risk is that of the network condition. There is a new contractor risk added where long term contract financing is part of the contract and that is cash flow. The cash flow of the project must be able to withstand the expected expenditure for the project to be viable. This must be managed throughout the project and the work strategies must be managed to ensure acceptable returns to the investors. The road authority has the risk that their performance measures may not reflect their requirements.

In Figure 1 the risk transfer linked to degrees of commercialisation options considered in Australia , USA and New Zealand (Haas and Yeaman, 2001) are illustrated and the potential commercialisation approach followed by the South African road authority Gautrans with own force routine road maintenance superimposed (Horak et al., 2004). From this it can be concluded that the risk could never fully be transferred from the client to the contractor..

Risk transfer does not necessarily mean better risk management. The transfer of risk from the road authority to the contractor only provides a benefit to the customer if the contractor is better able to manage the risk. The process relies on the accuracy and adequacy of the contractor's road management skills which in turn rely on the modelling system and data being used. And the process can never be robust in the face of uncertainty.

There is a key distinction between risk and uncertainty: risk is quantifiable, uncertainty is not. In the economics field, Keynes (1921) made a distinction between cardinal and ordinal probability. Cardinal probability is quantifiable: the probability of heads in a coin flip is 50 per cent. Ordinal probability is qualitative: for example, a road in a wet climate is more likely to deteriorate quickly than a road in a dry climate. But how much more quickly it will deteriorate, one can't say exactly. And it is uncertain how the climate will vary over the period of the contract. Model-based pavement management handles cardinal probability a lot better than ordinal probability.

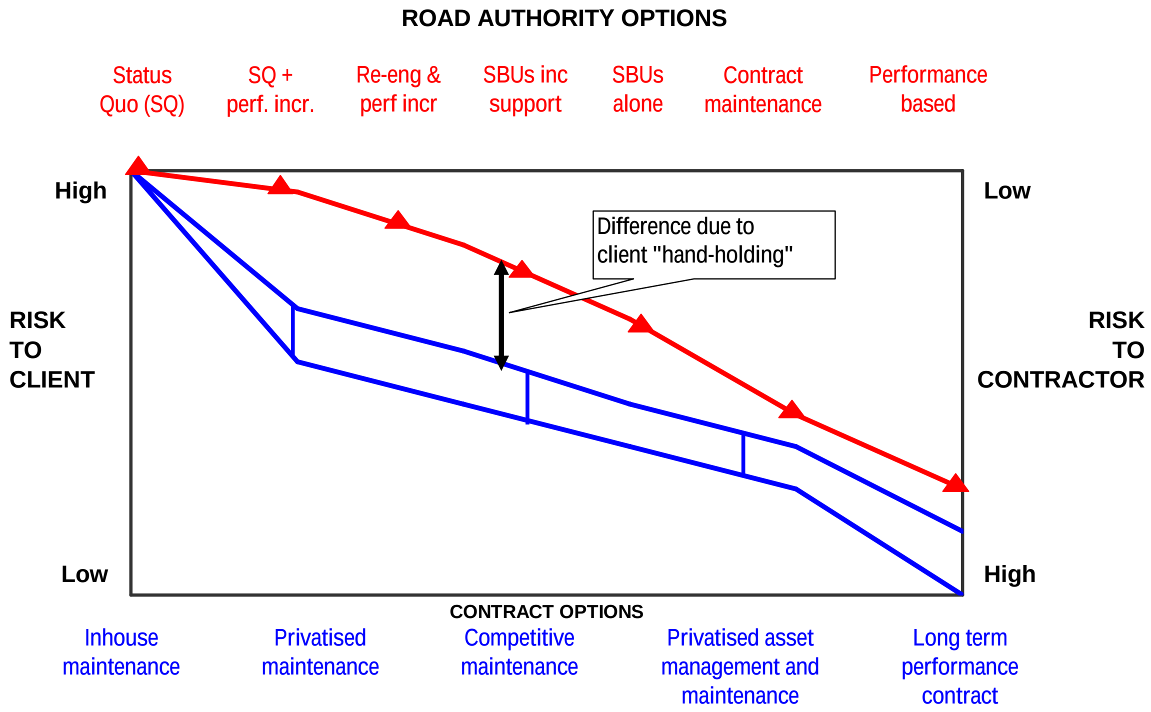

Figure 1: Risk versus commercialization contracting out options

3. TYPICAL PAVEMENT MANAGEMENT PROCESS

Pavement management systems differ in detail from road authority to road authority depending upon their specific needs (Olivier 1990). However the typical components and processes as inputs to the PMS are as follows :-

- Data storage. The database is the heart of a PMS, which is continually updated with pavement surveillance measurements, traffic data and as-built information. Much of the effort developing the PMS is in the establishment of the database and the manner in which large amounts of data are stored and retrieved.
- Data acquisition. There is an amount of data to be collected and periodically updated. With current systems, large amounts of data can be collected at high speed using sophisticated surveillance vehicles. Location referencing of all data is done using GPS technology. The processes of these data collection devices, their accuracy and limitations, have a substantial impact on the results and analysis using the data.
- Criteria. These are used in the evaluation of pavement condition and subsequent identification of maintenance or rehabilitation options. Minimum and maximum levels for the various criteria are defined, and form the basis of performance based contracts.

These basic components contain different elements and are used at both the network and project levels. Once the PMS is populated, it is used for analyses, performance modelling and optimisation.

Analyses, Performance Modelling And Optimisation

The essential function of the PMS at the network level is to evaluate the acquired data, using the stated criteria, so that a maintenance and rehabilitation program can be produced. Various analyses are carried out to obtain the following :-

- Present needs of the network.

- Distress predictions of the sections.
- Performance predictions of the sections and their future needs.
- Maintenance and rehabilitation alternatives for the network.
- Technical and economic evaluation of the appropriate or accept maintenance and rehabilitation alternatives.
- Priority analysis.
- Evaluation and optimisation of alternative budget levels.

Models have been developed to perform these analyses. The primary objective of modelling is reporting the current conditions and life-cycle predictions of future pavement performance for application in the management of road networks. The modelling starts with static models for the derivation of composite indicators, such as Key Performance Indicators (KPIs) (also called Key Performance Measures or KPMs). It extends through to future prediction using comprehensive dynamic pavement performance modelling of functional, structural, and works effects. KPIs relate to long-term pavement performance and define the drivers for a contractor's periodic maintenance and rehabilitation programmes. The models include strategic models based on a few individual measures and significant input parameters. These may be used to provide broad estimates of current and future conditions. Detailed modelling of functional and structural conditions and works effects (the impact of maintenance on conditions) is possible using interactive component incremental models (Austroads, 2009).

There is, to date, no uniformly accepted model for these analyses and evaluations. Road authorities have developed models to suit their specific needs, and these models differ markedly from one another. They all have the limitation that they have quantified the risk but not dealt with the uncertainties.

Panel Inspection

The PMS outputs a multi-year programme of works to maintain the network. The holistic approach to pavement management takes that works programme as an input, and adds engineering knowledge and skill through the panel inspection. This is one of the most critical components in the pavement management process. The panel inspection is typically expensive and hence it is often identified as an area to save costs. This results in a breakdown in the pavement management process with dire consequences.

Due to the complexity of pavement structures and uncertainties in materials behaviour, and notwithstanding the development of processes such as expert systems, artificial intelligence and finite element analysis, it is not possible to predict the performance of pavement structures using computer models with a high enough degree of certainty. An experienced pavement engineer is able to evaluate the distresses present, and together with the collected information, formulate an opinion on the performance and rehabilitation measures for a particular pavement or road, and holistically blend this opinion with the PMS output. Hence, engineering judgement especially at the network level, plays a significant role in the proper determination of the needs of the network and is the validation mechanism for estimating required quantities of work to achieve the KPIs.

However, without the panel inspection process, the uncertainties remain. Thus the panel inspection becomes a critical component in the maintenance and rehabilitation determination especially in performance based contracts. The experience of the panel inspections in the West Australian performance contracts showed the value of doing them jointly with the road authority and contractor. Parkman et al. (2003) give an example of texture depth and surface life KPIs. Normal resealing practice is to alternate with using small stone and large stone sizes, so that there is a natural periodicity over time in terms of texture variation. Similarly, surface life tends to fluctuate over time on a network. These fluctuations do not imply poor asset management practice, and to require they remain constant might in fact promote inefficient and ineffective practice.

4. PERFORMANCE BASED CONTRACTS – WESTERN AUSTRALIA EXPERIENCE

Western Australia

The road network is currently maintained through a series of 10 year performance based maintenance contracts. At their inception, they were held to be the most advanced of their kind in the world. In their final months now, it is evident that these performance contracts have not been particularly successful.

Road operation, maintenance and rehabilitation for the entire State was put out to eight separate contracts for a 10 year term, in 1999-2001. Six of the eight were performance based contracts where the outcomes for both short term maintenance requirements and long-term asset condition were specified and the contractor was paid a lump sum amount to deliver the asset management and road maintenance functions required to satisfy those specified outcomes (Noble, 2004). The other two contracts were schedule of rates type contracts where the on-road works are specified by the road authority, Main Roads Western Australia.

As the 10 year terms are expiring, only one of the six performance contracts remains intact[1]. The others have been converted away from performance contracts to a cost-plus model where the road authority shares responsibility and decision making for asset management and road maintenance. In this paper, this is referred to as a "breakdown" in the performance contract.

The state of the roads on the five ex-performance contracts is way below expectation. It is much better though on the remaining performance contract – TNC 8 – and the two mixed-type contracts. The Western Australia Auditor General reported on the state of roads (WA-AG, 2009) as follows:

> *Almost 10 years ago Main Roads WA changed the way it addressed this challenge by contracting out the maintenance of the state road network. This was a major shift in how Main Roads went about its maintenance business that no other state or territory had made. However, we found that the contracting of road maintenance has not delivered the expected results.*

with some of their key findings as follows:

- *Roads are at increased risk of structural failure because levels of planned maintenance have declined over the past 10 years – resurfacing by 30 per cent and rebuilding by 80 per cent.*
- *Planned maintenance has declined, mainly because the road maintenance contracts did not adequately specify road condition measures that would deliver the necessary planned maintenance.*
- *The estimated cost of eliminating existing overdue maintenance may exceed $A800 million* (The authors note that the population of Western Australian is 2.3 million; thus the cost is almost $A350 per head).
- *Contract prices have increased. Expenditure under the 10 year contracts is likely to be $467 million (59 per cent) greater than estimated in 1999. The major reason for this is the increase in global oil prices.*
- *Weaknesses in the contracts have meant that Main Roads could not adequately ensure the contractors met all agreed outcomes.*
- *Responsibility for any deterioration in the road network was not effectively transferred to the contractors; there is a risk the state will bear the cost of any work to restore the network to its previous condition.*

[1] TNC 8 – Perth Metropolitan North - Best Roads Group (for whom 3 of the authors provided the asset management and part of the road network managing services).

- *Main Roads lacks some key information about the condition of roads to accurately determine when, where and what type of maintenance needs to be done to ensure the cost effectiveness of future work.*

The amount of resurfacing and rebuilding done on the network during the performance contracts can be compared to historical levels (WA-AG, 2009)(Figure 2).

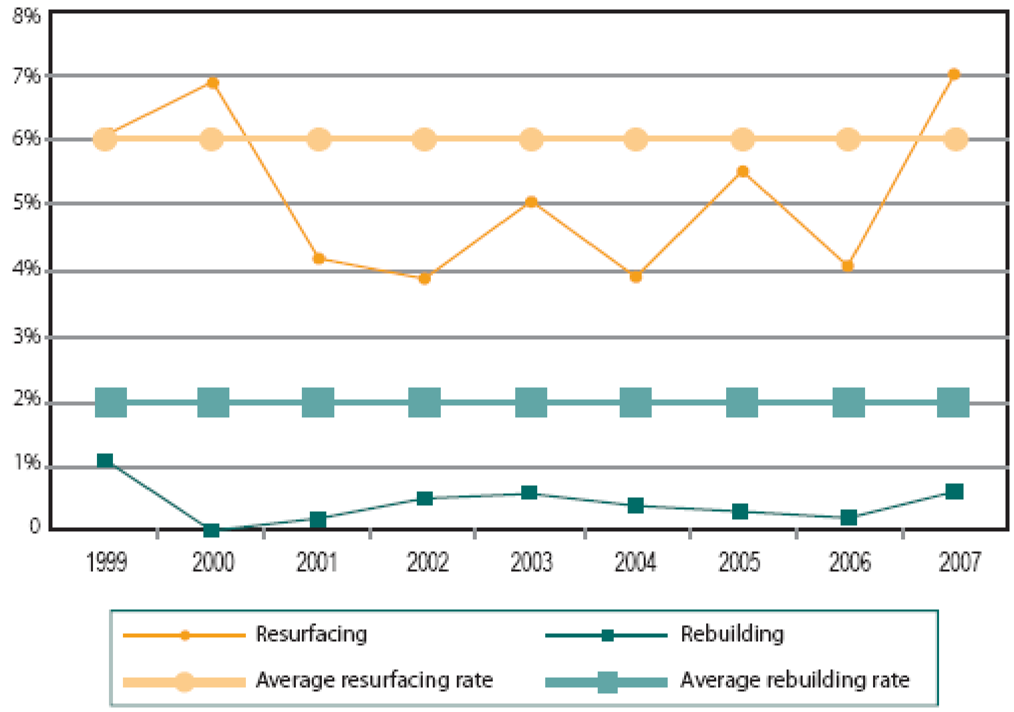

Figure 2 The percentage of resurfacing and rebuilding done on the network from 1999 to 2007

There has been a significant loss of intellectual capital and leadership in the road authority. As the Auditor General said: "*Main Roads has lost much of its technical expertise over the term of the contracts"* (WA-AG, 2009). Prior to the contracts, Main Roads had its own pavement design manual (a hybrid of Austroads and own empirical methods), its own seal and sand-prime design manuals, and its own test methods. As the 10 year period of contracts draws to a close, these have wholly or largely moved away from the Main Roads intellectual capital. The loss of higher level engineering skills has meant that major technical crises, such as the under-performance of hydrated cement treated crushed rock basecourse, have not been able to be resolved through good engineering leadership.

Expected constraints on performance contracts

The introduction of performance contracts were anticipated to have constraints, and Austroads (2003) identified some which might limit the wide-scale adoption of performance contracts. The extent to which these constraints occurred in the West Australian performance contracts is presented in Table 1.

Table 1 Occurrence of anticipated constraints on Western Australian performance contracts

Anticipated constraint	Actual constraint in WA performance contracts
1. How to Define the Performance Required	Yes - problems continue with performance indicators and models.
2 How to Measure Performance	Yes - problems continue with measuring remaining life.
3 The Cost of Tendering	Possibly – cost is very high, and only large parties are able to tender for the contracts.
4 The Ability to Justify the Benefits	Yes – not value for money. The acid test is long-term performance and whether level of service meet expectations and tendered price remains intact over contract period. Both missed substantially.
5 Lack of Experience or Preparedness (in both the Industry and RAs).	Yes – breakdown of some contracts was linked to lack of road network managing skills in contractors.
6 Lack of Robust Asset Data	Yes – problems with asset data in urban areas continues.
7 Ability to Forecast Future Condition	Yes - confidence levels in deterioration models remains a problem.
8 Regional Development and Employment	Yes – there was a social cost to rural communities.
9 Risk of Consequence of Failure	Yes - the monthly payment system meant that total payment was well advance of the value of work completed i.e. contractor had a programme with many major treatments toward the end of the contract period. There were serious differentials for the contracts that broke down.

Parkman et al. (2003) identified similar issues, including the key point that methodologies to predict pavement performance need to go considerably beyond the original methodologies in identifying and interpreting the risks involved. Models such as the World Bank HDM only go a limited way towards addressing the KPMs. Key parameter models tend to have low correlation coefficients due to the variability of the data used and other factors inherent to the sample data used in the development of such models.

And finally, there is obvious commercial contracting constraint that overshadows all fixed price fully outcomes based performance contracts. The only way that the contractor can increase profit is to decrease expenditure. This is detrimental to the road condition and road users. By doing nothing, the contractor actually increases profits. The experience of these contracts suggests there is merit in the form of future performance contracts which include minimum annual works requirements (such as tonnes of asphalt and lane-kilometres of reseal).

Modelling the network condition

Management of the structural condition of the network, and in particular the means for avoiding the consumption of the asset, were important attributes of these performance contracts. They used indicators such as maximum deflection, radius of curvature, rutting, roughness and cracking index, as well as a strength restoration measure (deficit in gravel thickness).

In preparation for tendering the performance contracts, and during the contract, the road authority annually undertook Falling Weight Deflectometer (FWD) surveys of the entire network. The spacing of the FWD tests were 800m apart, which proved to be far too large, usually generating too few test points per uniform section. The result was lowered confidence in the data, and difficulty in calibrating deterioration models. Over and above this, Horak and Emery (2006) indicated that there are problems with the use of only maximum deflection and radius of curvature. This is due to limitations of the whole pavement response, and to the FWD measuring technology being used as a replacement of the empirically based Benkelman beam.

The TNC 8 network was a mixture of rural and urban roads, and problems were experienced with data consistency including registration (up to a 40m shift from year to year), varying start/end points for dual carriageways each year, and urban area-specific problems which are discussed in the subsection below.

The PMS used on the TNC 8 network was the PERS system, and using its capabilities the network was divided into 100m sections and individual deterioration models were applied to every 100m section. Bounds were set to ensure reasonableness of the models. For roughness deterioration, reasonable models could only be obtained for 448 out of 5470 sections. For rut depth deterioration, reasonable models could only be obtained for 1393 out of 5470 sections. The fit of individual models varied from good to poor, and the roughness on numerous sections even improved over time (Figure 3).

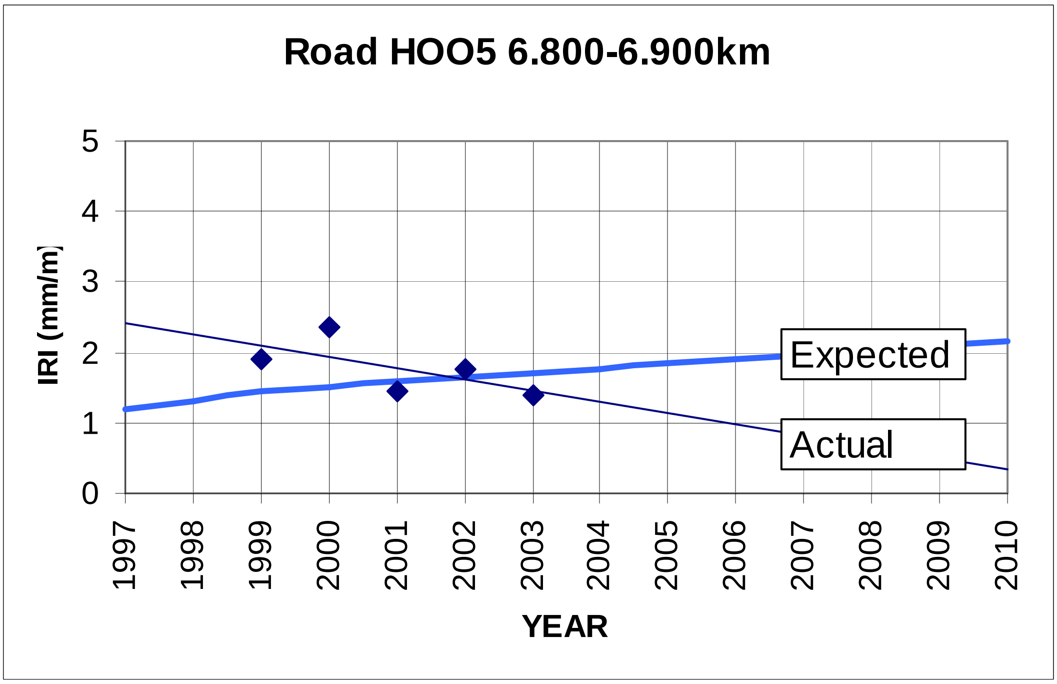

Figure 3 Poor fit of roughness deterioration model to data for 1999 - 2003

The maximum deflection and radius of curvature were used in the performance contracts to determine the structural strength of each pavement segment and as measures with respect to pavement strengthening and asset consumption. The empirical relationships as contained in the Austroads (1992) pavement design guide were specified to determine pavement remaining life and base condition. These measures proved to be inaccurate as there was no correlation between the remaining life and base condition as well as no correlation with these measures and that experienced in the field. Parkman et al. (2003) reported similar concerns in New Zealand:

> *. . . experience in New Zealand with the HDM models is now beginning to suggest that calibration factors (and even model forms) might be significantly different from the original HDM equations. For example, it appears at this stage that roughness deterioration rates are significantly lower than the default HDM equations (down to possibly 20 – 30%). . . .*
> *. . . . there remains a concern that rehabilitation type activities (traditionally driven by roughness in the HDM models) are being driven by other mechanisms (pavement shear failure and unstable surfacings).*

The variability of FWD maximum deflection over time and spatial distance was such that often no model could reasonably be fitted to the data on the TNC 8 network. An example of 10 years of maximum deflection data over a 50km length of highway is shown in Figure 4.

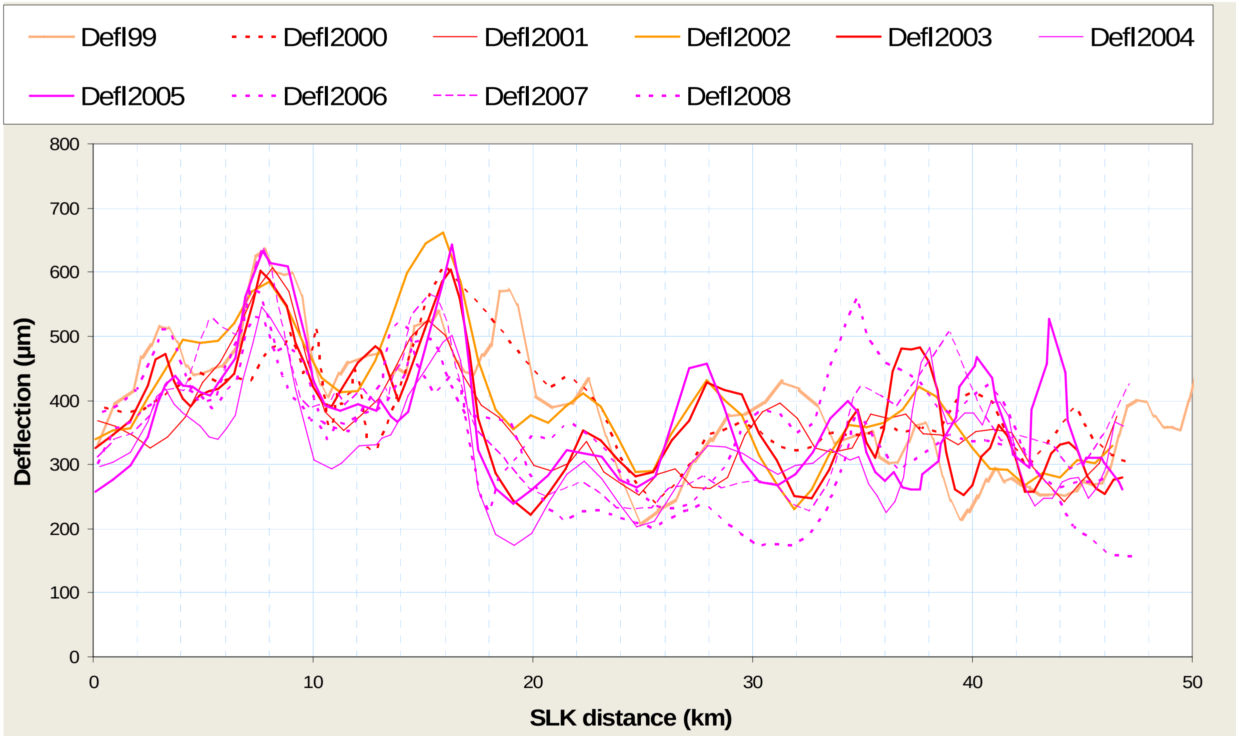

Figure 4 FWD maximum deflection 1999-2008 over 50km of highway H005

Difficulties in modelling urban networks

Measures used for performance modelling have been derived from rural roads. Difficulties have been reported by others (Agrawal and Henning, 2005) in adapting these to urban roads. On the TNC 8 network, there was a mix of road classes varying from urban freeways, to major urban arterials to single carriageway rural roads.

During the Panel inspection it was evident that on some urban roads the measured condition data was triggering pavement repairs on sections of road that did not need repair. This was not usually a problem on the rural roads. Furthermore as the Panel progressed, it was evident that in isolated places, reported roughness values were well above the real roughness value. Roughness was measured by laser profilometer, which is commonly used instead of response-type equipment. The profilometer measures the elevation of the wheel paths to form longitudinal profiles. These profiles are computed to derive International Roughness Index (IRI) using various mathematical curve fitting functions. In turn IRI is converted into the Australian roughness measure (NAASRA) using a simple mathematical expression. The curve fitting functions may work well on rural roads, but can give rise to problems on urban roads.

It became apparent that below a speed of 30 kph, roughness measuring drops out, with the accelerometers/lasers either spiking or automatically excluding (cutting out). This is not significant on rural networks, but is a problem on urban networks. It was occurring at traffic lights, and due to queuing, for up to 400m before the traffic light. The occurrence varied randomly from year to year and varied with each annual set of data collected. This is an inherent limitation of the measuring system. Also at slip lanes (such as the end of a highway), there were some records of high roughness where the cornering speed was not low enough to trigger exclusion but was high enough to give a false roughness. Near intersections, there were some spots with false high roughness that might have been due to braking for traffic where the braked speed was not low enough to trigger exclusion. In other cases the peculiarity of crowned urban road profiles at intersections were observed to give true roughness measurements requiring milling and "smoothing", but the geometry of the intersection mean that this was just not practical from a height restriction (kerbs and drainage) point of view. Such problems could only be clearly identified with the help of visual inspection.

Agrawal and Henning (2005) had reported that steep gradients and tight curves had an impact on roughness readings. High roughness was observed by them on sections with gradient greater than 10% and curves with radius less than 100m. They found sections had high roughness particularly at start and end 40m as compared to the remaining length, and noticed high roughness for the data collected at low speed. Their average roughness was up to 250 NAASRA at speed less than 30km/h (equivalent to an IRI of 9.6).

In addition to reported roughness spots that were simply not there, there were some genuine roughness spots over drainage grates, manholes, painted lines and other urban features. Some spots should be repaired but there were some genuine roughness spots for which it was not good engineering practice to repair until the next road reconstruction/overlay. Others could simply not be removed due the nature of the physical feature. There were even some where the roughness was designed in by good engineering practice such as an intersection surfaced in asphalt with the road either side being sealed.

Partway through the contract, the upgraded Hawkeye video system became available and was matched with collected data. This showed that some high roughness values were being triggered by white lines (such as stop bars) or in one case what looked like a small paint spill on the road, yet the matching camera views showed no road roughness and the Panel inspection a few days previously had found that those sections were smooth. In one case, a manhole cover (not an open grate) triggered a 10 metre long section of high roughness, and a short distance down the road, another cover (which looked identical to the first) triggered a 30m section of high roughness. This suggests that the curve fitting function to convert profile to roughness is being thrown off intermittently by these urban obstacles. The Hawkeye showed a drainage grate which was in the laser line and which had triggered a high roughness, and other drainage grates which were not in the laser line and did not trigger high roughness, and yet more grates where their concrete surround was in the laser line and the [not rough] surround had triggered high roughness. These are all typically urban problems. This phenomenon also varied from one year to the next as it was dependent on the exact travelled line of the surveillance vehicle. That meant that in one year a particular drainage gate would be picked up as being rough but the next year it would not be picked up and the roughness reported as smooth.

Asset Condition Profiles

A feature of the Western Australian performance contracts was the use of Road Maintenance Intervention Parameters (RMIPs) to define the short-term maintenance requirements and Asset Condition Profiles (ACPs) to define the long-term requirements (Noble et al., 2003). It was believed that if RMIPs were the only standards specified, there was a significant risk that over the life of the contracts the network would deteriorate to those standards. To ensure that the road network would not deteriorate past a condition considered appropriate, ACPs were applied for the attributes of roughness, rutting, texture, surface skid resistance and residual pavement design life.

ACPs describe the distribution of the condition of the attributes on each road link. The ACPs were described at three levels, the baseline or distribution of each attribute at the commencement of the contract, the target or minimum final distribution required at the conclusion of the contract and the worst allowable distribution below which the contractor shall not allow that link to fall during the contract period. The target and worst allowable condition profiles were not in themselves a desired condition. They were the result of treating an existing network according to a strategic modelling setup, i.e. purely mathematical outputs from a set of rules covering typical deterioration rates, treatment triggers and condition resets following treatment .

The use of ACPs caused significant problems. On many roads, the ACP’s failed to meet the targets, which was a significant contractual issue. Kennedy and Peters (2008) identified a number of reasons for this, including:

- At the time of preparing the contract, the ACP targets were generated from a desktop study (analysis) which applied treatments to the roads based on their current and predicted conditions, as well as the expected improvements (resets) to the condition once a treatment was applied. However there was no field verification as to the reasonableness of the treatments applied or assumed resets gained.

- The urban road measurement problem meant that some treatments are inappropriate and carrying out a treatment with an expected big improvement in condition will not materialise. Hence the predicted condition of the road and its target were not attainable.
- Some of the resets were not reasonable. such as "all existing rutting will be reset to zero by a reseal". After applying a seal, there will be little change in rutting and the end result would be a new surfacing on a road that is well within performance criteria, buts fails to meet a predicted target.

The net result of using ACPs was that if the target were to be attained, it would have resulted in large sums of money being spent on maintenance and rehabilitation treatments in order to simply satisfy a computer model and hence a contractual requirement rather than spending the money for good engineering reasons and hence good asset management. They were counter-intuitive to holistic pavement management. On TNC 8 (the only long term performance based contract to run its full course) these problems mentioned earlier were picked up very early on. Notwithstanding the rigidity of contractual management practice of the road authority, open communication and understanding of the ACP philosophy by the contractor and advisors led to joint annual panel inspections with road authority representatives. This helped to identify these anomalies and facilitated joint acceptance of proposed remedial measures if and where needed. It served to highlight the importance of joint panel inspections with road authority and contractor.

5. PERFORMANCE BASED CONTRACTS - SOUTH AFRICAN EXPERIENCE

South African Experience

Performance based contracts on road networks in South Africa are limited to two types of contracts: the Product Performance Guarantee System (PPGS) type contract and the DBO toll road concession type contract.

PPGS contracts were employed on a limited scale in the early 1990's but did not progress further. Their guarantee periods were typically 4 to 6 years and they were essentially a guarantee of a product for a period of time. Due to their limited use they had little effect on the process or outcomes of PMSs.

The first long-term performance based contract for road pavements was awarded in the mid 1990's for the section of the National Route 1 from Bela Bela to Polokwane (Alli and Smit, 2004) . The Contract period for this section is 23 years. The basis of this contract was finance, design, construct and maintain with no traffic risk to the contractor.

Subsequently three toll concession contracts, each with a 30 year contract period, have been employed on other national routes. These are the National Route 4 between Pretoria and Maputo (Alexander et al, 2004), the National Route 3 between Heidelberg and Pietermaritzburg and the National Route 1/National Route 4 between Pretoria to Bela Bela on the N1 and between Pretoria and Lobatse (the Botswana boarder) on the N4. The basis of these contracts are finance, design, construct, maintain and operate. The concessionaire takes full risk for the road pavements over the concession period and it includes the traffic risk, which are subject to minimum performance criteria. The experience documented in this paper is based on that gained on the National Route 1/National Route 4 toll concession; currently the contract is in its ninth year of the 30 year contract.

Performance Requirements

The contract performance requirements have 3 phases. The first phase is to bring the facility up to minimum standards within the first 3 years of the contract (the Initial Construction Works). Thereafter the second phase is to maintain the facility to minimum levels of performance throughout the remainder of the contract period. The third and final phase is to return the facility to the road authority with certain additional minimum condition criteria. These include the requirement that a minimum structural condition or pavement strength be present in each road section on handing back the facility at the end of the concession period.

Typically, the performance requirements during the contract period are based on visual and functional requirements and it is only at the end of the contract period when the structural condition of the facility is measured against performance criteria. However, it is accepted, at least to pavement engineers, that the structural condition of the pavement has a large influence on the functional and visual condition, and hence cannot be ignored. Table 2 details the typical performance criteria that the facility is subject to at any point in time during the concession period and the frequency within which measurements are taken to ensure compliance to the performance criteria.

Table 2 – Performance Measures for Flexible Pavements

Performance Measure		**Frequency**
Functional	Roughness	Annual
	Rut depth	Every two years
	Texture depth	Every two years
Structural	Visual assessment	Annual
	Deflection measurements	Every three years

Achieving Performance Requirements

A PMS was implemented at the completion of the initial construction works period. The system has the ability to :

- Store all measured data
- Predict performance based on empirical models
- Carry out mechanistic pavement analyses and using incremental recursive mechanistic modelling processes to predict structural and functional deterioration of the pavement
- Calibrate both empirical and mechanistic prediction models on each pavement section, using past performance data and therefore better predicting the future condition.
- Carrying out an economical analysis of each set of rehabilitation options so as to minimize whole of life costing.
- Carry out consequence analysis of the various rehabilitation actions and timing with respect to pavement performance in the short medium and long-term.
- Compare and optimise rehabilitation strategies with the upgrade strategies. This process also included human input with good engineering judgement.

The PMS processed data is used to monitor the condition of the network relative to the performance criteria. The short, medium and long-term rehabilitation actions are taken into account in monitoring and predicting the performance of the network to ensure the performance criteria are met.

Meeting Criteria vs. Preserving the Asset

One of the basic theories in monitoring a road network asset is to ensure timeous maintenance and rehabilitation, to ensure minimising whole of life costing, and to maximise the structural performance of the road pavement. This runs counter to the realities of toll concession type contracts when finance is used to fund the design, construction and maintenance activities. There, the intent is to delay high initial capital costs such as heavy rehabilitation for as long as possible.

The pitfall for these types of contracts is that if one purely considers the contractual performance criteria which typically reflect functional performance and only consider structural performance at end of the contract, the structural condition of the pavement could easily be ignored during the contract. Without a holistic approach to pavement management, it is possible but fallacious to believe that no maintenance and rehabilitation is required because the stipulated performance criteria are being met.

One of the typical outputs from a PMS is KPIs or measures. These are typically:

- Visual condition index
- Roughness
- Rut depth
- Skid resistance and/or macro-texture

Many assume that the structural condition or performance of a pavement is reflected in the abovementioned indicators or measures. For example, a deteriorating base layer results in roughness deterioration and/or an increase in rut depth as well as a decrease in the visual condition index. However this is not necessarily the case. Some performance contracts include explicit structural indicators such as a structural number calculation or limits to deflection. But these only give an indication of the overall pavement strength, and are not able to correctly predict or determine the performance of the pavement system as well as the performance of each layer within the pavement system.

This can be illustrated by an example using the abovementioned KPIs and is shown in Figures 5 and 6 below. This is a typical uniform pavement section which shows the deterioration over the last six years. In Figure 5 the average roughness and rut depth are shown since 2005 as well as the limiting performance levels for roughness and rut depth.

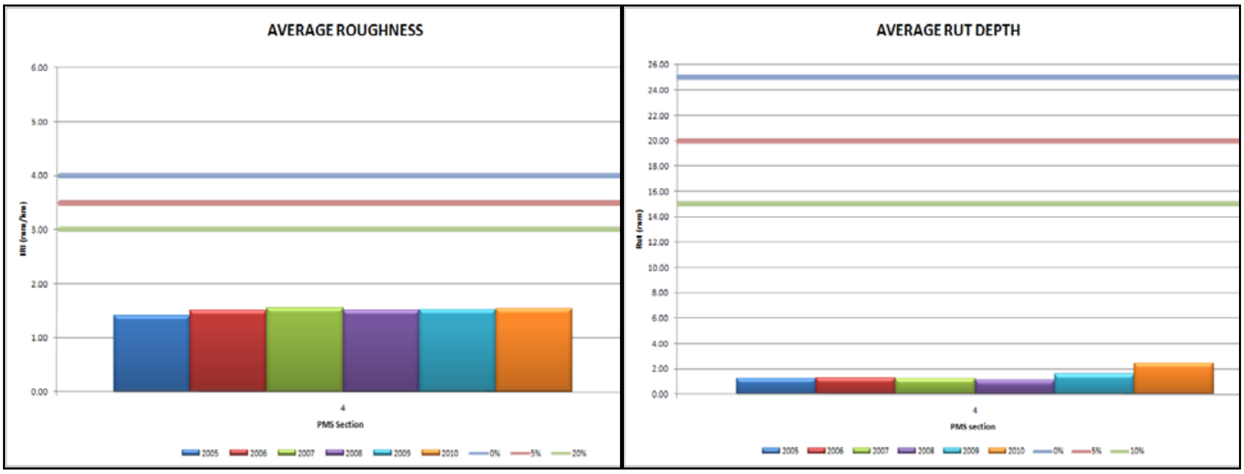

Figure 5: Average roughness & rut depth performance on a uniform pavement section

Figure 6 shows the visual condition index change since 2007 and the structural number change as measured every three years since 2004.

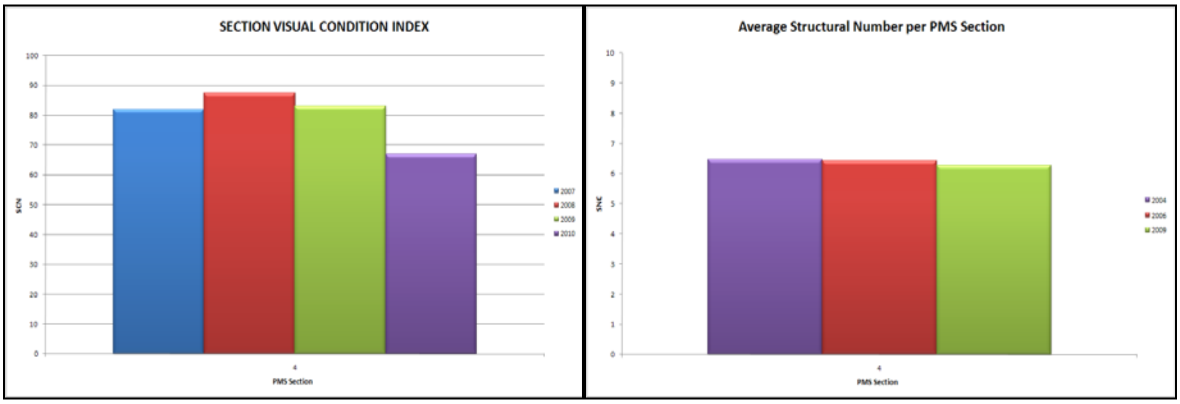

Figure 6: Average visual condition and structural number performance on a uniform pavement section

This uniform section as depicted in the above figures provides for an interesting case study. At first glance it looks to be performing well. As can be seen, the roughness and rut depth are well below any performance criteria limitations, and the rate of deterioration is very low. The visual condition index from 2007 to 2009 remained reasonably constant. The increase in visual condition index in 2008 was a result of the annual crack-sealing exercise. The structural number has deteriorated at a slow rate.

Considering only the above KPIs (except for the visual condition index in 2010 which is the first sign of some deterioration), there is nothing worrying in the performance indicators. The pavement is performing well within the specified performance criteria. However, during a panel inspection on this section in 2007, the panel became concerned at the overall type of distresses starting to manifest, although the distresses evident were isolated, They decided to initiate a pavement analysis which subsequently progressed to an extensive detail investigation of this section.

In 2009 the investigation concluded that notwithstanding the apparent good condition and slow rate of deterioration that in fact within the next few years the pavement would require heavy rehabilitation, and if this were delayed then the accelerating rate of deterioration would result in later very heavy extensive rehabilitation and/or reconstruction. This had neither been planned for nor identified by the KPIs. It required the holistic approach to pavement management, combining sophisticated modelling with engineering judgement via the panel inspections.

The two lessons to be learnt are firstly the value of the panel inspection and secondly that due to the complexity of pavements, KPIs are typically only reactive and are not sufficient on their own to control these types of longer term contract periods. Management of pavement networks is a proactive process. Had it not been for the panel inspection the first signs of a problem would only have been identified some four years later when it had become much more serious. But now, the concessionaire has had time to investigate and plan to ensure that the asset is correctly preserved whilst meeting performance criteria.

A very similar experience occurred on the Western Australian TNC8 performance contract where an incipient disintegration of a freeway surfacing was picked up the panel inspection despite the KPIs being excellent. This was unanticipated and caused significant re-juggling of the works programme over several years. This issue is nicely summarised in the Auditor General report (WA-AG, 2009) which stated:

> *The state's roads are generally smooth but smoothness alone does not give an indication of the underlying structure of the road. There are occasions when a smooth surface may conceal a weak road, at risk of or close to failure. A smooth surface can be delivered by frequent maintenance like fixing potholes and smoothing cracks as they appear.*

6. DISCUSSION: WHAT DIRECTION FORWARD FOR PERFORMANCE CONTRACTS?

Performance based road management and maintenance contracts are a feature of modern road management. They were developed and implemented in Australia, New Zealand, Latin America, and North America and since then have spread to Europe, Asia, and Africa, promoted by international development institutions like the World Bank. These contracts rely heavily on good PMSs and processes to meet the contractual framework of condition targets and intervention parameters. Earlier practitioners identified a number of constraints which might limit the wide-scale adoption of performance contracts. But in the period prior to the major long-term performance contracts being let, hubris developed in parts of the PMS industry, and in the roads community more generally, that everything could be precisely measured and priced. In particular, long-term road performance and the risks over a long period of operation could be quantified. Our experience from such performance contracts in Australia and South Africa has found that this is not so.

We are not saying that the quest for precise measurability was misplaced. There has been a lot of progress made in better understanding the way that roads perform and enhancing the technology of pavement management. The problem is that the scope of pavement management proved to be too narrow. The focus tended to be on modelling the things that were quantifiable to the exclusion of those which were not. Some risks were treated as cardinal even though they were actually ordinal. Some issues such as data measurement problems and inability to correctly and accurately model pavement performance were neglected. Moreover, the modelling was often based on too short a history. Comfort was taken in the precision of the measurement without thinking enough beyond the measurement. That is, not enough judgement was exercised. Indeed, it seems to have often been turned off.

An important element of road management is to know what you don't know. But unfortunately even that is not good enough. The purist fully outcomes-based point of view is that ultimately you can measure what you don't know. That, we believe, is inherently impossible, and is the challenge ahead for performance contracts.

Because it is impossible to model all aspects of road condition perfectly, we should make future performance based contracts as robust as possible to uncertainty, while realising that it is not possible to insulate them completely from uncertainty. We do not believe that ‘the Truth is out there’ waiting to be discovered to correct the situation. The systems faction in pavement management systems, to some extent, is on a quest to find ‘the Truth’ through ever more sophisticated data collection equipment and modelling systems. But as Debelle (2010) stated:

> *"While a valiant quest, with much knowledge to be gained in its pursuit, like Lancelot's quest for the Holy Grail, it is likely to be in vain."*

A critical issue for the future face of PSMC performance contracts is: how do we cope with uncertainty? The answer is that it depends on the circumstances. In the traditional model of road maintenance, not being able to quantify the risk of the unknowable, or take into account the uncertainties, is not that important provided the road authority has the engineering ability to juggle programmes, budgets and priorities. However, in the form of 10-year performance contract that some Australian road authorities entered into, it becomes the main game. The flexibility of the performance contract was very limited. These were contracts, and were administered by contract administrators. They were not road network operations administered holistically by experienced road engineers. There was little or no provision for the juggling of programmes, budgets and priorities. Even where there was nominal scope in the contract for variation through a "management board", this proved to be nominal and not effective.

The strict contractual management approach leaves limited room for manoeuvre and input from engineering knowledge if the base or original uncertainty regarding the road network condition and possible deterioration mechanism is not well defined and quantified at the inception stage. This level of insight is clearly beyond the normal PMS survey and modelling level. This apparent undervaluation of the base uncertainty has clearly also contributed to the limited success of the PSMC performance contracts as observed in Western Australia.

The experience on TNC8 was that it took exceptional relationship management skills to involve the road authority in the annual panel inspections to help identify anomalies and solutions within the contract boundaries. The other five performance contracts in WA ran into trouble and ended up as cost plus maintenance contracts. Australia has made considerable headway with alliancing and partnering contracts where risk is shared via in-depth workshops involving both client and contractor. The results from these type of contracts are still “spotty” as success ultimately relies on soft issues such as trust and openness which can fail due to lack of expertise on both sides of the table.

In the case of the toll concessionaire contracts in South Africa, they are long-term contracts where the concessionaire effectively carries the full risk for the pavement performance over 35-37 years (due to the requirement to hand the facility back with a minimum structural strength). There is the ability to juggle programmes, budgets and priorities within the contract period, albeit within some pre-arranged finance structure, which can limit the extent of the juggling. However the total budget throughout the 30 year period is not flexible to large increases. This places enormous responsibility on the concessionaire to ensure that his PMSs and processes are at a sufficient level of expertise to ensure that holistic pavement engineering is undertaken.

It is often financiers and contractors who package and lead these contracts, but they have little experience or skill in pavement management processes. The way forward for these contracts is to ensure that both the road authority in terms of prescribing the contract conditions and the concessionaire in carrying out his obligations provide sufficient levels of skill to minimise the cardinal risk and to best manage the ordinal risk associated with the pavement asset. The uncertainties inherent in the total road and pavement system need further research and analysis before risk can be better defined for road authority and contractor. The scope goes beyond normal PMS level investigations and is often not done in sufficient detail given the uncertainties involved.

The experiences on performance based contracts both in Australia and South Arica have similarities and differences. The key to the performance based contracts is the need to have holistic pavement management systems and processes. The most notable is the input of experienced pavement engineers. Systems are critical in providing the information, but it is ultimately the experienced engineer who needs to process this information to ensure good asset management.

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