IMPROVED CONSTRUCTION PRACTICES: PAVEMENT PERFORMANCE EVALUATION AS AN INPUT TO STOCHASTIC ASSET MANAGEMENT

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SYNOPSIS

In the construction of pavements and surfacings, the contractor is starting to encounter contracts that require them to share or assume some guarantee on performance. This can take the form of an extended warranty (such as a 5 year warranty for surfacings built under the South African PPGS scheme), or a long term responsibility for the performance of the road and surfacing (such as in a long term maintenance contract). This paper deals with costing that responsibility. Since most of these contracts apply to existing roads, the focus is on the surfacing/resurfacing.

The choice of surfacing is reasonable straightforward, and there is general knowledge amongst road authorities, suppliers, contractors and consultants as to the correct type(s) of surfacing/resurfacing to use.

The challenge for the contractor is to price the cost of possible repairs to meet the performance warranty over its term. This will depend on the underlying pavement and the expected surfacing/resurfacing performance. In the first generation warranty costing, the cost was calculated for tendering purposes using the Bayesian decision tree, which is stochastic in nature. These are already used by road authorities for stochastic asset management. A simple but practical example is given for a five-year warranty on thin asphalt.

A new generation warranty costing method is proposed that addresses the limitations of the first generation method, and is expanded to cover the full spectrum of pavement performance criteria. Decision trees are presented which can be used for to estimate the type and therefore the cost of rectification of each failure. The probability of failure is found using contractor's experience and judgement, and the warranty cost is then calculated. The result is a quantitative model that can be used for pricing the risk and cost of asset management.

1 INTRODUCTION

1.1 Improved construction practices

Construction practice in roads is changing as road authorities across the world turn to structures that provide for the road authority to own the asset, and outsource the management and delivery. While procedural (or method) specifications have traditionally been used for roads, the move towards performance (or functional or end product) specifications is occurring as a result of these road authority changes. Performance specifications encourage innovation as contractors find the best way of meeting the performance requirements. They tend also to require the contractor to share or assume some of the risk of the road owner and designer.

The sharing of risk means new responsibilities and roles for the contractor. These can include design responsibility, asset management responsibility and/or performance responsibility. They require new skills and practices to be used to manage risks and to price them. These new contracts typically make provision for a guarantee of performance. This can take the form of an extended warranty offered by the contractor (such as a 5 year warranty for surfacings built under the South African PPGS or Product Performance Guarantee System scheme). It could also be the long term responsibility for the performance of the road and surfacing (such as in a long term maintenance contract).

1.2 Pavement performance evaluation

The performance of the road system is dependent on the features of the asset, its condition and use (Norwell and Youdale, 1997). Road users will assess the acceptability of the service provided by the road transport system based on a number of factors. Those relating to pavement performance are:

- Reliability and accessibility (time between failures, limitations on frequency of maintenance and thus limits to cracking, failures, dry/brittle condition and ravelling),
- Travel comfort and ride quality (smoothness, shape, ruts),
- Road safety (skid resistance, bleeding, ruts, surface unevenness, potholes),
- Cost of using the system such as tyres, fuel, vehicle repairs (potholes),
- Travel time (delays due to maintenance),
- Costs of constructing and maintaining the system (time between failures, limitations on frequency of maintenance).

For pavement engineering purposes, the performance factors can be simplified down to a few, such as skid resistance, surfacing condition, shape, deformation, etc. These are the factors that will be increasingly used by the road authorities to measure the performance of the pavement.

When a contractor becomes responsible for the performance of the pavement, then they must evaluate the performance of their own product. The traditional quality control tests used for roads such particle size distribution, plasticity index, layer thickness, bitumen viscosity, softening point, Marshall stability, stone spread rate, and so on, are difficult or impossible to relate to pavement performance. New measures of pavement performance evaluation need to be introduced.

1.3   Stochastic asset management

One of the new responsibilities and roles for the contractor in performance contracts is asset management. After construction and after the works have been opened to traffic, the contractor will be responsible for the performance of the end product for a period (known as the warranty period). Performance can be defined as the level at which the products perform after a predefined period of time, measured against predetermined requirements for the particular product (BMLC, 1994). In the event of the product not achieving the required performance level, the contractor is wholly or partly responsible for any remedial action required enabling the design requirements or performance levels to be met.

This puts the contractor into a similar position to a road authority in terms of needing to manage the road during the warranty period, and this is best tackled if the contractor uses some of the road authority's tools. Stochastic asset management is one such tool, which uses the laws of probability for managing the asset. It is common to find in road asset management because the performance of a surfacing or section of road is always open to a measure of uncertainty, and this can be handled on a probabilistic basis.

For the contractor, stochastic asset management techniques can be used to price the cost of repairs and maintenance to meet the performance guarantee over the term of the contract. This paper outlines this and presents a new method for doing so which can be used in practice.

## 2   COSTING THE PERFORMANCE WARRANTY

2.1   First generation warranty
The first generation approach to costing the performance warranty for the contractor was developed by a simple combination of Bayesian decision tree and experience. Because PPGS was initially limited to resurfacing on structural sound pavements (Burger, 1999), this reduced the complexity of failure possibilities, and made such warranty analysis easy.

The approach is best illustrated by an example. Consider a PPGS project of 4 kilometres resurfacing with a Stone Mastic Asphalt overlay 40mm thick. The road is a 2 lane national highway (which in South Africa is 12,2 metres wide, including the surfaced and trafficable shoulders). The cost of the surfacing only (excluding preliminary and general costs, traffic control, etc) at R210 per tonne laid, would be R983 808.

A performance warranty of 5 years is to be provided in this example. The cost of warranty in the first generation approach is found by using a decision tree to estimate possible outcomes during that 5 year period. For this example, there are 2 outcomes: failure of the SMA within the 5 years (5% probability), and success of the SMA (95% probability). Note that the probabilities in a decision tree must add to 100%. The decision tree is shown in Figure 1.

Figure 1   Decision tree
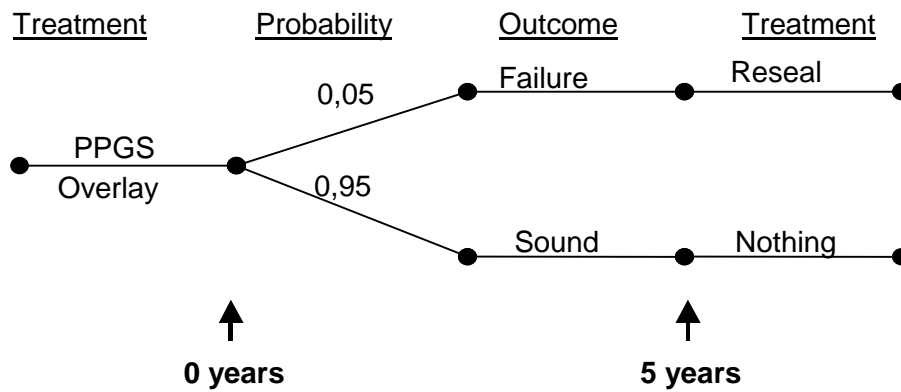
The decision tree is not as quite as unsophisticated as it seems. In practice, all the possible failure modes would have been discussed by the contractor's tendering team, their likelihood estimated, and the most probable repair estimated based on experience.

For this example, the most likely scenario is that the whole length would have to be repaired using a single seal with unmodified bitumen[1]. The total cost for this, at a reseal cost of R5 per square metre, and allowing 20% of the reseal cost for mobilisation and traffic control, would be R292 800.

The cost of the warranty was calculated as shown in Table 1, and for this example is R14 640. It is expected that the contractor would establish what is essentially a self-insurance scheme, and would bank the warranty provision of R14 640 into a reserve account.

Table 1   First generation warranty costing

Treatment	Cost	Probability	P x Cost
Partial Reseal	R 292,800	0,05	R 14,640
Nil	Nil	0,95	R0
		Total	R 14,640

Note 1USD=6.3 Rand 1AUD=4.0 Rand - Approx

Intuitively this seems rather a small warranty provision, and the type and probability of failure have influenced it substantially. It implies that only one project in 20 will have a problem, which is rather optimistic for some contractors. If there were 1 in 10 projects with a problem, then the probability of failure would be 10%, and the cost of the warranty would be R 29,280.

In addition to the warranty provision, the contractor typically must also lodge a performance bond. For this example, a performance bond of R250 000 for the full 5 year period was assumed, and the cost of the performance bond was assumed to be 0,5% per year for each of the five years.

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[1] In South Africa, modified bitumen means the addition of a polymer such as SBS or rubber-crumb. Unmodified bitumen is normal hot bitumen.

The tendered price for this example would be made up of P&Gs (mobilise/demobilise), traffic control, surfacing, warranty, and the cost of the performance bond (Table 2). Profit is assumed to be built into the line items.

Table 2   Tender price with first generation warranty

ITEM	Units	Rate	Cost
P&G and traffic	Item	R100 000	R100 000
Surfacing	4684.8 tonnes	R210	R983 808
Warranty	Item	R14,640	R 14,640
Performance bond	Item	0,5%	R 6 250
Total			R 1,104,698

Note 1USD=6.3 Rand 1AUD=4.0 Rand - Approx

The first generation warranty costing had the advantage that it was easy to use, and took full advantage of the contractor's experience in setting probabilities and cost levels[2]. Because it could be intuitively grasped, the warranty could be turned over and over until it really did represent quite a good approximation of reality.

2.2   Limitations of the first generation warranty

There were a number of issues that were not properly addressed in the first generation warranty:

- There was no time value of money built in, in the sense that later repairs would discount back to a lower value at tender time in terms of Present Worth of Cost,
- There was no explicit capability to handle more than one failure occurring during the warranty period, other than informally. In the example above, the contractor could have added R5 000 to the cost of the partial reseal to cover some pothole repairs.
- The ability to consider more than one failure mode (ie ravelling in one section and potholing in another) is limited. It can be informally built into the cost of repair, but it very quickly gets too complex to consider. With the new performance based contracts covering many criteria for failure (rutting, stone loss, skid resistance, etc), no one yet has the experience to judge the probability for all of them.
- There is inadequate provision for unlikely but expensive repairs such as full length mill and replace.

2.3   Length of warranty

The length of warranty relative to the design life of the product is important to address. The first generation warranty took no account of the fact that as the road gets older, it runs the risk of incurring normal long term or 'end of design life' failure (as opposed to 'construction-associated' or 'poor-design' failure).

To understand this better, we need to go back to the concept of PPGS, wherein the warranty is that "the products perform after a predefined period of time … measured against predetermined requirements for the particular product". Such a warranty will

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[2] In the construction business, it is often considered better to back the experienced contractor's judgement than rely on complex theoretical calculation.

be breached if the products fall below the requirements (fail) before the predefined time. Such failure can be envisaged in three time brackets:

Construction failure is typically the case of poor workmanship. It occurs at or shortly after construction (due to defective binder, poor application or mixing, poor laying or compaction, etc). The risk of this type of failure is well understood, and the contractor already has its cost and probability implicitly built into the pricing. This is not really part of the warranty process.

Warranty failure is the case where the products fail after construction but before the predefined period of time. For example, a stone mastic asphalt that should have lasted 10 years, was warranted for 5 years, and failed after 3 years. This failure could be due to poor design or materials, or the product may have been the wrong one for the job, or the product may have been improperly specified or improperly applied.

End of design life failure is the case where the product reaches the end of its design life before the end of the warranty period. Such failure is unexpected, because in PPGS warranties, the length of warranty is typically set at much less than the design life of the product. In South Africa this has commonly been 5 or 6 years for surfacings that should last 10 years (50-60% of design life). However new research is showing how variable the design life of the surfacing actually is.

Jooste (1999) shows how the sort of real spatial variations in parameters such as asphalt thickness, asphalt stiffness, and base stiffness and thickness can lead to considerable variations in predicted design life. These variations lead to uncertainty in predicted performance. Thus a new surfacing which should have a life of say 10 years, may actually have a life varying from much less to much more, due to real variations in its properties.

To delve into that issue, which concerns the location and shape of the pavement life distribution, is not possible in this paper. However an idea of the likelihood distribution of failures over time can be had from the Texas Pavement Management Information System (PMIS). Pilson and Hudson (1999) presented some models for prediction of failures on four road sections. The models were in the general PMIS form of sigmoidal models and used five parameters for defining this sigmoidal curve. The modified version of the sigmoidal equation for the prediction of distress extent is as follows:

$$L = \gamma + \alpha e^{-\left[\frac{\rho}{y-\delta}\right]^{\beta}}$$ ....(1)

where γ, α, ρ, δ, and β are the five parameters, L is the distress and y is the year of the prediction. The models for the four sections as defined by their parameters are given along with inventory information in Table 3.

Table 3: Model and inventory information for sections

Highway	Begin Reference (miles)	End Reference (miles)	Sigmoidal Model Parameters				
			α	β	δ	ρ	γ
SH0037	K 222.0	222.5	500	1.36	1986.0	30.1	0
SH0037	K 222.5	223.0	500	1.36	1984.5	38.3	0
SH0037	K 223.0	223.5	500	1.36	1984.5	38.3	0
SH0037	K 223.5	224.0	500	1.36	1983.7	43.3	0

Plotting these models gives the predicted number of failures per section of 0.5 miles length (Figure 2). The model does not predict the type of failure or the extent of failure, but it can be seen that the number of failures rises sharply after the five year point for those road sections.

Figure 2   Predicted number of failures per section (Texas PMIS)
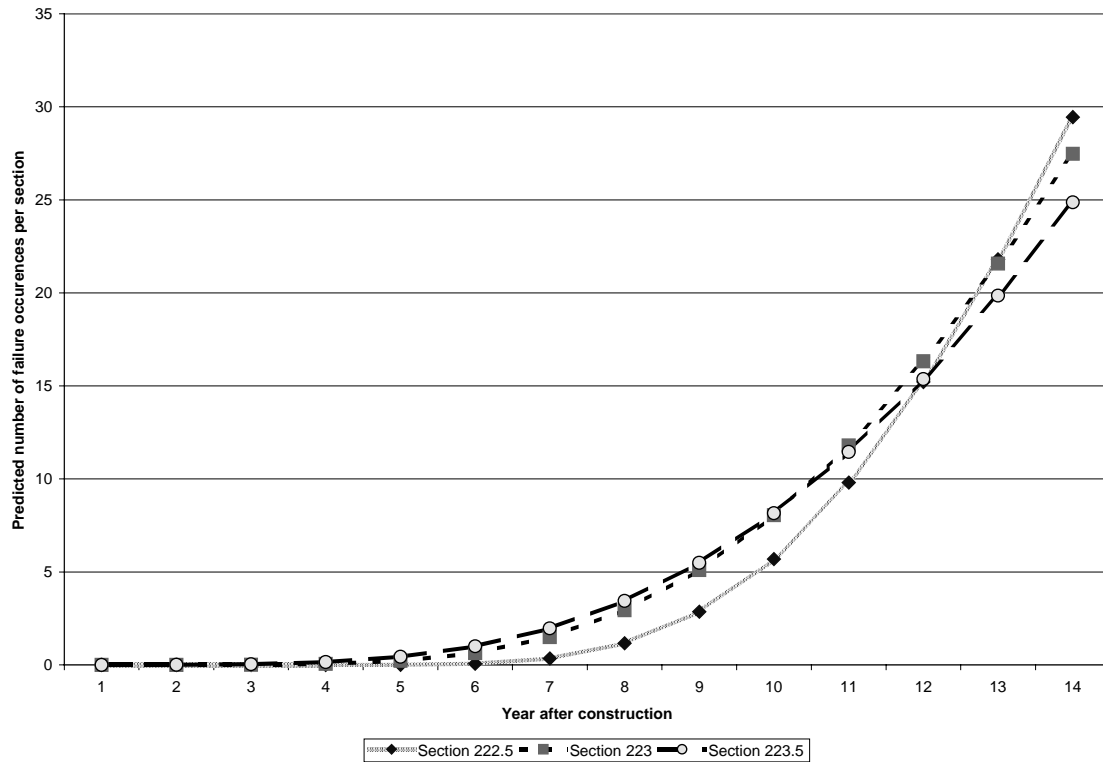
There is a clear link between the length of the warranty period, and the possibility of encountering early 'end of design life' failures. However while the data from Texas illustrate the problem well, they are not easily translated into this probability analysis. A 'failure' in their terminology may be as small as a single pothole, which is different to the medium/large failures considered in the analysis in this paper. The incorporation of the risk associated with 'end of design life' failure into the calculation of warranty cost is simply too complex at this stage. It would need substantial additional PMS performance data and would be likely to be modelled with the Beta probability distribution function.

The best method for controlling this risk in practice is suggested as limiting the warranty period to 50 or 60% of the design life at this stage, since beyond that, the risk rises sharply.

3   NEW GENERATION OF PERFORMANCE WARRANTY

The new generation of warranty proposed in this paper addresses some of the defects of the first generation performance warranty. It provides a framework to address performance based specification requirements, and simplifies this to a warranty that can be costed practically in tendering.

3.1 Time value of money

Normal economic analysis would provide for later year repairs to be discounted back to a lower value at tender time in terms of Present Worth of Cost. To do this the time of repair would need to be known. A reasonable stochastic approximation for time of failure is the uniform probability distribution function (with an equal chance of failure at any time during the warranty period). A simpler approximation is to find the average of the discount rates for each year. This was done for the data in the example above. The discount factor rate was found for each year using a discount rate of 8% (6% would be more applicable in Australia). The average of the discount factor rates was 0,798542, which indicates that including the time value of money would give approximately a 20% reduction in the warranty cost.

However it is suggested here that the time value of money should not be applied to costing this type of contractor warranty for the following reason. Assuming nil inflation, the repairs in the example would cost R292 800 at any time during the warranty period. It is assumed that the contractor will establish a self-insurance scheme for warranties, and will be banking the warranty provision of R14 640 into a warranty reserve. At nil inflation, the return on bank investments will also be minimal, perhaps 2 or 3%. So the warranty reserve will earn little return and the contractor will have paid almost the entire cost of the warranty. For practical purposes, the time value of money can be ignored.

The same argument holds true if inflation is running at say 10%. At this level, the bank investment return would be (10% + 2-3%), say 12 or 13%. Again the warranty reserve investment will grow only very slightly faster than money looses value through inflation, and again the time value of money can be ignored.

The new generation of warranty should therefore ignore the time value of money for warranties (at least for 5/6 years or less).

3.2 More than one significant failure occurring during the warranty period

The probability of more than one significant failure occurring during the warranty period can be estimated using the Poisson Distribution. It is more common in quality control to consider probability of failure (p) in terms of the Binominal distribution, where we take a sample of definite size and count the number of times a certain event (e.g. the occurrence of a failure) is observed. However on roads, we are dealing with the occurrence of a number of isolated failures in a continuum of length. In such cases, the binominal distribution is inapplicable because we do not know the value of n in the fundamental expression $(p+q)^n$, but the Poisson distribution is.

The Poisson distribution was applied using data from commercial practice in South Africa[3]. The number of failures per year was estimated in terms of:

- Minor failures (typically resolved on site, and less than 50 tonnes asphalt or equivalent)
- Medium failures (typically resolved at State or Provincial level at a typical cost of R50 000)
- Large failures (typically resolved at national level at a cost in excess of R250 000)

The minor failures were not included in further analysis since they were considered to be part of normal operations. The average number of medium and large failures

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[3] Data from Colas Southern Africa, adjusted to maintain their commercial confidence.

combined per year was Z = 0,05. This means that a company with 100 projects per year would expect a frequency of significant failures of 0,05 x 100 = 5 per year.

The probabilities of 0, 1, 2, 3, 4, etc significant failures per year per project was then found by evaluating the Poisson distribution (Table 4).

Table 4   Expected significant failures per year per project

Number of significant failures per project per year	Probability
0	95.1229%
1	4.7561%
2	0.1189%
3	0.0020%
4	0.0000%
5	0.0000%
6	0.0000%

Thus the probability of a single significant failure on a project is 4.7561% and the probability of 2 significant failures on a project is 4.7561% + 0.1189% = 4.8750%, which is little changed from the one significant failure case. For practical purposes, the occurrence of more than one significant failure during the warranty period can be ignored.

3.3   Ability to consider more than one failure mode

The ability to consider more than one failure mode (ie ravelling in one section and potholing in another) is seen as important for the new performance based contracts which cover many criteria for failure. Since the cost of repair varies widely according to the type of failure, an individual assessment of each will enable a better estimate to be made of the total warranty provision.

The types of performance specifications in use generally have the following criteria (Cabana et al, 1999):

- Surfacing Condition Index (typically computed from surfacing failures, surfacing cracks[4], aggregate loss, dry/brittle condition, and bleeding),
- Roughness,
- Rut depth,
- Structural or fatigue cracking,
- Ravelling,
- Skid resistance.

Where the road fails to meet the performance specification, it will need to be repaired during the warranty period by the contractor. The cost of the warranty is linked to the cost of these repairs. The type of repair for each type of failure can be found from the new decision trees presented in this paper. The contractor's experience and judgement provide the probability of each failure type occurring.

The decision trees are derived from a comprehensive resurfacing selection chart that was developed in South Africa, bringing together seals, slurries, microsurfacings, and the various types of asphalts. It also incorporated modified bitumens such as SBS, SBR, and bitumen-rubber (Colas, 1996). The origins of this chart were in much simpler road authority decision trees, together with inputs from a panel of pavement and surfacing engineers (Bergh, A; Emery, S; Van Rijckevorsel, T; Van Zyl, G).

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[4] as opposed to structural or fatigue cracks

For this paper, the chart has been modified and adapted to use with performance criteria, and is presented in the following figures:

Figure 3   Decision tree for roughness and fatigue cracking
Figure 4   Decision tree for rutting
Figure 5   Decision tree for surface cracking and ravelling/dry
Figure 6   Decision tree for bleeding/skid resistance

These decision trees can be used for each project to estimate the type and cost of rectification for each failure type. They make it easy for contractors to bring their experience and judgement into play to estimate the probability of each failure type. They also allow unlikely but expensive repairs to be included in the costing.

Figure 3   Decision tree for roughness and fatigue cracking
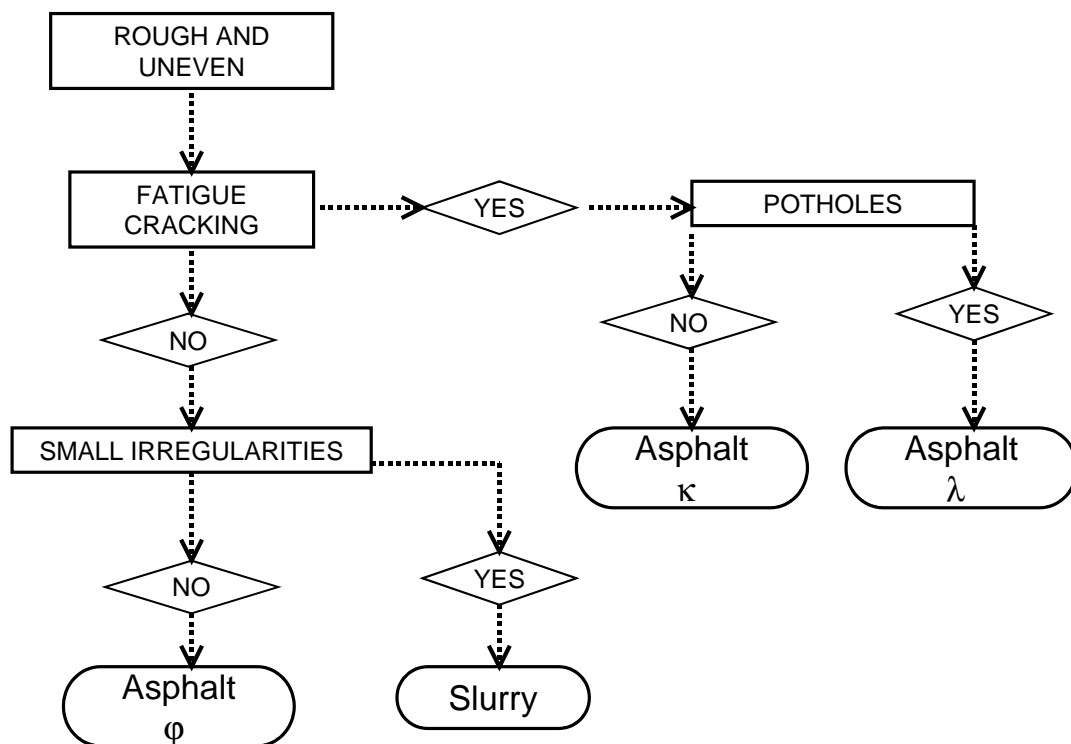
Notes:
Asphalt ①   SGG asphalt (semi-gap graded);
                   AC (continuous graded asphalt);
                   Microsurfacing
Asphalt ②   SGG 40 (40mm thickness) + PCC (precoated chip rolled in);
                   SGG modified (bitumen) 40 + PCC;
                   SMA (stone mastic asphalt) 30
                   Mill and replace
Asphalt ③   Patch + SGG modified 40 + PCC;
                   Patch + SMA 40;
                   Cold insitu recycling + overlay seal / AC / SGG

Figure 4   Decision tree for rutting
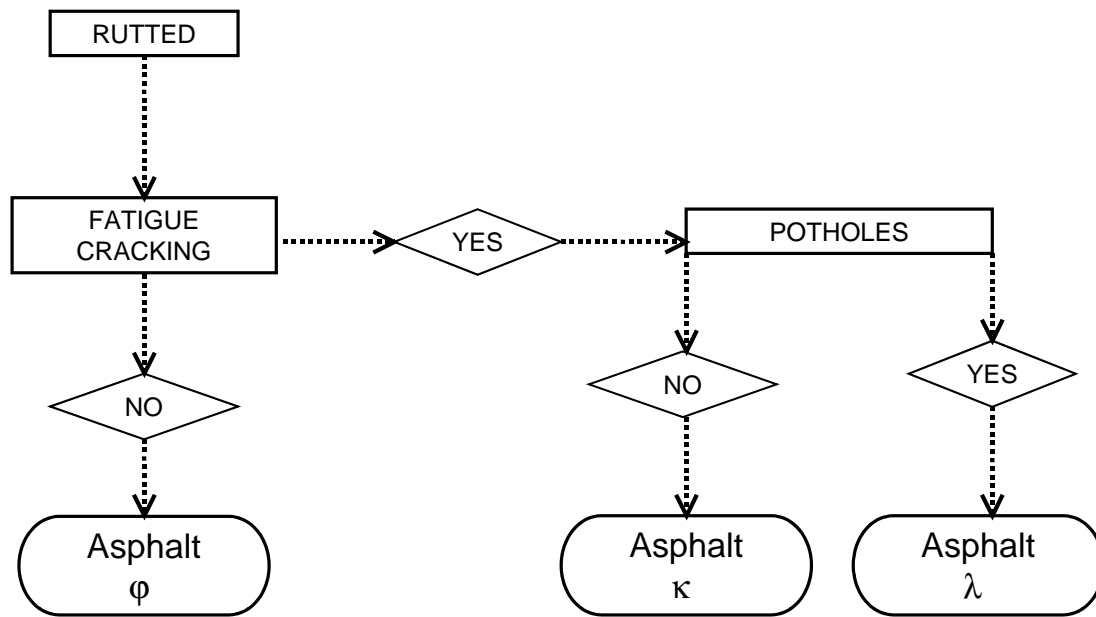
Notes: see Figure 3 for explanatory notes

The use of the decision trees can be illustrated by returning to the example used earlier in this paper: a PPGS project of 4 kilometres resurfacing with a Stone Mastic Asphalt (SMA) overlay 40mm thick.   The repair method and probability were estimated for each of the performance criteria: roughness and fatigue cracking, rutting, surfacing cracking, ravelling/dry, and skid resistance/bleeding. In the process, Table 5 was used to link contractor judgement to probability.

**Table 5   Contractor judgement and probability**

Contractor judgement	Probability
Technically reviewed and not expected	0%
Unlikely	1%
Possible	5%

Roughness and fatigue cracking
Roughness could be expected to develop in either the pavement or the resurfacing. A pavement engineer reviewed the strength of the pavement and the forecast traffic over the warranty period[5], and the pavement was judged adequate and deflections assessed as low. Fatigue or structural cracking is therefore not expected by the contractor (probability 0%). Small irregularities could occur in the surfacing if it was faulty. There is, for the purposes of this example, limited experience by the contractor with SMA, so they judge that this is possible (probability 5%). The repair would likely be limited to one or two days production (say 5000 square metres), and (from Figure 3) could be patched by a slurry.

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[5] In South Africa, the client may do this and the information included in the tender documents, or the contractor may do it.

Figure 5   Decision tree for surfacing cracking and ravelling/dry
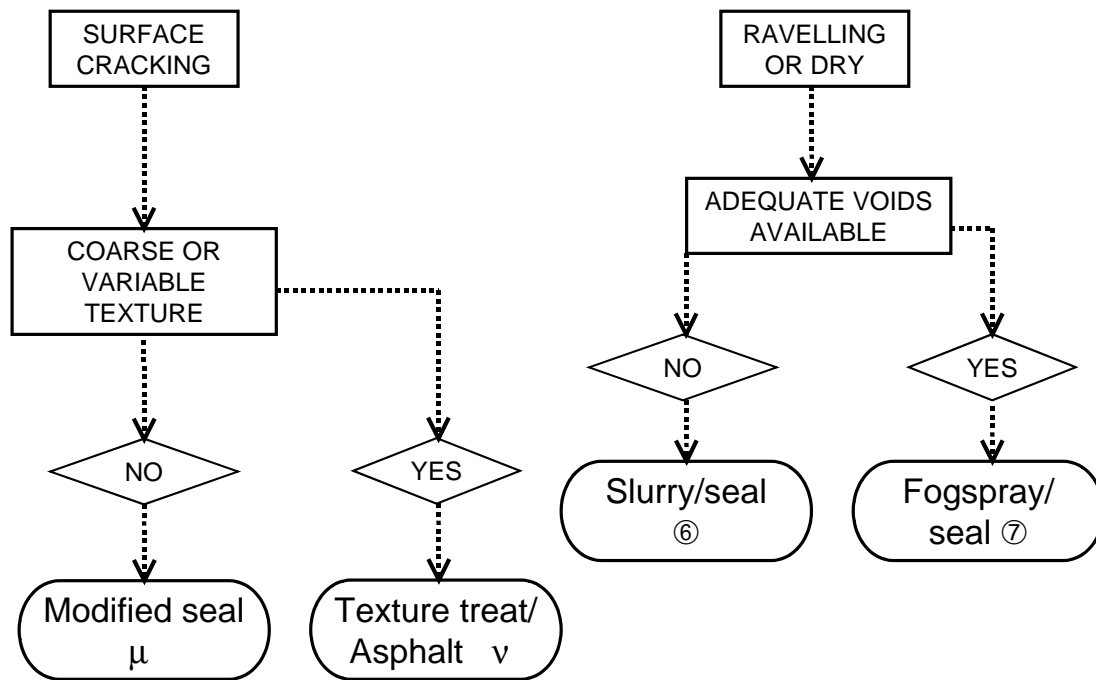
Notes:

Modified seal④   Modified bitumen single seal;
                        Ultrathin asphalt surfacing (Novachip or similar).

Texture treat/Asphalt ⑤   TT (see below for explanation) + modified single seal;
                        SGG 30 + PCC 13mm;
                        AC 25.

Slurry/seal ⑥   Microsurfacing or slurry;
                        AC 25;
                        Single seal;
                        Ultrathin asphalt surfacing.

Fogspray/seal ⑦   Fogspray (dilute emulsion);
                        Sand seal or single seal;
                        Microsurfacing or slurry;
                        Ultrathin asphalt surfacing.

TT   Texture treatment Varying texture is commonly seen as bleeding in
      the wheeltracks and dry between the wheeltracks. To pre-treat this prior
      to resurfacing, it is common to use a texture treatment in South Africa.
      For very light traffic, they apply a sand seal, or for light to medium traffic,
      they apply a thin slurry or microsurfacing.

Rutting

Rutting could be expected to develop in either the pavement or the resurfacing. Again, the pavement was adequate and deflections assessed as low. Fatigue or structural cracking and rutting from the pavement are not expected by the contractor (probability 0%). Rutting could occur in the surfacing if it deformed under traffic. There is limited experience of the contractor with SMA, so this is possible (probability 5%). The repair would be full length, and (from Figure 4) would be a microsurfacing.

Figure 6   Decision tree for bleeding/skid resistance

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                        ┌──────────────┐
                        │  BLEEDING/   │
                        │    SKID      │
                        │  RESISTANCE  │
                        └──────┬───────┘
                               ┆
                        ┌──────▼───────┐
                        │  VARIABLE    │
              ┌┄┄┄┄┄┄┄┄┄┤   TEXTURE    ├┄┄┄┄┄┄┄┄┄┐
              ┆         └──────────────┘         ┆
           ┌──▼──┐                            ┌──▼──┐
           │ NO  │                            │ YES │
           └──┬──┘                            └──┬──┘
              ┆                                  ┆
       ╭──────▼──────────╮            ╭──────────▼────────╮
       │ Seal/inverted   │            │ Texture treatment/│
       │ seal/           │            │ Asphalt      ⑨    │
       │ porous asphalt ⑧│            │                   │
       ╰─────────────────╯            ╰───────────────────╯
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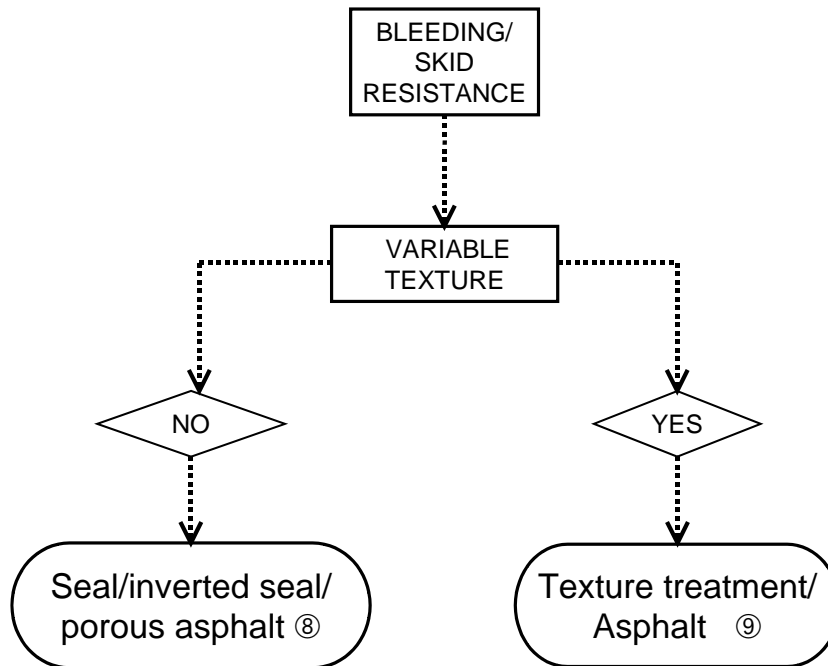
Notes:
Seal/inverted seal/porous asphalt ⑧:
         Modified bitumen single seal;
         Double seal or inverted double seal (larger stone on top);
         Microsurfacing;
         AC Porous 40.
Texture treatment/Asphalt ⑨:
         TT (see Figure 5 for explanation) + single seal;
         SGG 30 + PCC 13mm;
         Microsurfacing.

<u>Surface cracking</u>
Surface cracking could be expected to develop in the resurfacing only if it was defective. This is considered unlikely (probability 1%), but if it occurred it would likely be an inherent defect in the whole surfacing. The surface texture of the SMA would be coarse but probably not variable, so the repair would be full length, and (from Figure 5), would be a modified bitumen single seal.

<u>Ravelling/dry</u>
Ravelling could be expected to develop in the SMA if it or the binder was defective. Given the contractor's limited experience with SMA, this is possible (probability 5%), and if it occurred it would be an inherent defect in the whole surfacing. The surface texture of the SMA would be coarse and so there would be adequate voids available. The repair would be full length, and (from Figure 5) would be a single seal. The fogspray is an alternative but was considered too risky.

<u>Bleeding/skid</u>
Bleeding and/or skid resistance problems would be likely to be inter-related for this surfacing. Bleeding would be expected to develop in the SMA only if it was defective. Given the contractor's limited experience with SMA, this is possible (probability 5%),

and if it occurred it would be an inherent defect in the whole surfacing. The surface texture of the SMA would be unlikely to be variable. The repair would be full length, and (from Figure 6) would be a modified bitumen single seal.

3.4   Calculation of new generation warranty costing

The calculation of the new generation warranty costing starts with the matrix of failures, probabilities, extent, and repairs, shown in Table 6. The cost of repairs is given in Table 7, and the warranty costing in Table 8.

Table 6   Matrix of failures, probabilities, extent, and repairs

FAILURE	PROBABILITY	EXTENT	REPAIR
Roughness and structural cracking	5%	5000 sq.m.	Slurry
Rutting	5%	full	Microsurfacing
Surface cracking	1%	full	Modified single seal
Ravelling/dry	5%	full	Single seal
Bleeding/skid resistance	5%	full	Modified single seal

Table 7   Cost of repairs

REPAIR	COST/SQ.M.
Slurry	R 3.75
Microsurfacing	R 5.50
Modified single seal	R 6.50
Single seal	R 4.50

Table 8   Warranty costing

FAILURE	PROBABILITY	EXTENT	RATE	COST	P x COST
Roughness and structural cracking	5%	5000 sq.m.	R 3.75	R 18,750	*R 938*
Rutting	5%	48800 sq.m.	R 5.50	R 268,400	*R 13,420*
Surface cracking	1%	48800 sq.m.	R 6.50	R 317,200	*R 3,172*
Ravelling/dry	5%	48800 sq.m.	R 4.50	R 219,600	*R 10,980*
Bleeding/skid resistance	5%	48800 sq.m.	R 6.50	R 317,200	*R 15,860*
				Total	*R 44,370*

Note 1USD=6.3 Rand 1AUD=4.0 Rand - Approx

The warranty costing is R44 370, when all the possible modes of failure are considered. This would change the tender price of the example originally shown in Table 2, to be as shown in Table 9.

Table 9   Tender price with new generation warranty

ITEM	Units	Rate	Cost
P&G and traffic	Item	R100 000	R100 000
Surfacing	4684.8 tonnes	R210	R983 808
Warranty	Item	R44,370	R 44,370
Performance bond	Item	0,5%	R 6 250
Total			R 1,134,428

Note 1USD=6.3 Rand 1AUD=4.0 Rand - Approx

The cost of warranty (including cost of performance bond), as a percentage of the total price, changes from 1,89% in the first generation warranty costing to 4,46% for the new generation warranty costing, which intuitively feels a much better provision.

4   CONCLUSIONS

When the contractor encounters contracts that require them to share or assume some guarantee on performance, the warranty must be costed. The first generation approach to costing a warranty was a simple combination of Bayesian decision tree and experience. The first generation warranty costing had the advantage that it was easy to use, and took full advantage of the contractor's experience in setting probabilities and cost levels. However there were several issues that were not properly addressed in the first generation warranty:

The new generation of warranty costing proposed here addresses the defects and provides a framework to bring in all the performance based specification requirements. It has the following features:

- The time value of money is not required to be considered,
- Only a single failure occurrence needs to be considered in the warranty period,
- The new performance based specifications are addressed, covering criteria for failure such as roughness, fatigue or structural cracking, rutting, surface cracking, ravelling, dry condition, bleeding and skid resistance. Decision trees are provided which can be used to estimate the repair for each type of performance failure, and therefore the cost of rectification. They allow the probability of each failure type to be more easily provided by the contractor's experience and judgement.

The incorporation of the risk associated with 'end of design life' failure into the calculation of warranty cost is best controlled in practice by limiting the warranty period to 50 or 60% of the design life.

The new generation warranty costing is comprehensive but sufficiently simple to be used when tendering to estimate the cost of providing a performance warranty.

REFERENCES

Burger, D. (1999) PPGS: its implementation in South Africa. 7th Conf. Asphalt Pavements Southern Africa, Victoria Falls

BMLC (1994)   Product Performance Guarantee System (PPGS) - Framework Document Executive Summary.   Bituminous Materials Liaison Committee Task Group on PPGS, DRTT-CSIR, Pretoria

Cabana, G., Liautaud , G., and Faiz, A (1999)   Areawide Performance-Based Rehabilitation and Maintenance Contracts for Low-Volume Roads.   Seventh International Conference on Low-Volume Roads, Baton Rouge, Louisiana

Colas (1996) Products and Services Handbook. Johannesburg

Jooste, F.J. (1999) The Influence Of Variability On Routine Pavement Design. 7th Conf. Asphalt Pavements Southern Africa, Victoria Falls

Norwell, G and Youdale, G (1997) Managing the road asset in Australia and New Zealand. Routes, Vol 296, 13 November.

Pilson, C. and Hudson, R. (1999) Use of genetic algorithms for solution of pavement design and maintenance optimisation problems. 7th Conf. Asphalt Pavements Southern Africa, Victoria Falls