TREATMENT PERFORMANCE CAPACITY – CONCEPT VALIDATION

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ABSTRACT

Road departments employ a variety of pavement preservation treatments to maintain and preserve their network of paved highways. In this paper a model was developed to relate asphalt treatment life in terms of Treatment Performance Capacity (TPC), pavement condition, traffic level and location temperatures for all asphalt based treatments. This model is able to provide estimates of the performance of treatments, in several climatic zones, several pavement condition levels and traffic magnitudes. Using the TPC values for each treatment and the price of each treatment, the cost effectiveness for all treatments was developed. This paper also presents several examples that validate the concepts behind the model.

1 INTRODUCTION

Road departments employ a variety of pavement preservation (preventive or corrective maintenance) treatments to maintain and preserve their network of paved highways. The primary purpose of a proactive pavement preservation program is to delay the need for costly pavement rehabilitation or reconstruction as noted in the California Department of Transportation Maintenance Technical Advisory Guide (Caltrans 2003). The purpose of this paper is to estimate, in a rational manner, the pavement treatment life and the associated development of the Treatment Performance Capacity (TPC). This paper is based on the reports and papers produced by Sousa and Way (Sousa, 2007) and Sousa Volumes 1 and 2 (Sousa, 2009); and the subjective and empirical data developed by the California Pavement Preservation Task Group (PPTG); and data and numerous studies conducted in Arizona (Kaloush, 2002), (Way, 1976), (Way, 1979), (Way,1980), and (Zborowski and Kaloush,2006). Further validation of these concepts is also presented based on the Federal Highway Administration accelerated loading facility (ALF), (Qi 2008) and Arizona data (Carlson 2009).

All the treatments involve asphalt based materials and range from thin surfacing like a fog or rejuvenating seal to thin overlays such as a 25mm hot mix asphalt (HMA) overlays. It is recognized that heavy traffic affects treatment lives more than light traffic. The model was developed based on traffic index (TI) as used by Caltrans which can be easily converted to the standard AASHTO 18-kip equivalent single axle loads (ESAL's) by Equation 1 (AASHTO, 1993).

$$TI = 9.0 \times \left(\frac{ESALs}{10^6} \right)^{0.119} \qquad [1]$$

The estimated life information compiled in this document is based on the collective experience of the California Pavement Preservation Task Group (PPTG) to which the experience and best engineering judgment of a few experts in the industry were added. The extensive empirical tables prepared by the PPTG relating treatment duration to TI, percent cracking and location are presented in reports by Sousa and Way (2007) and Sousa (2009).

The time of placement of the treatments can influence the performance of the treatment. In other words, treatments placed on good pavements will last longer than treatments placed on bad pavements. Many times, a treatment is scheduled to be placed on a good pavement, but by the time it is actually placed, the condition of the pavement has deteriorated and this will affect the expected life of the treatment. The models developed in this study are limited by this observation of actual practice. To the degree practical, the model in this report address the lives of the treatment as a function of the level of traffic and climate (coastal, valley, mountains, and desert) in which the treatment is placed.

2 STUDY APPROACH-ESTIMATING TREATMENT LIVES

The initial estimates of lives of treatment were first developed by the PPTG strategy selection committee. It was considered that the expected life of a treatment and life extension would be influenced by the climate. To this effect, the performance grade (PG) climate map was utilized where California was divided into four climatic zones. It was recognized that traffic is also a key aspect that affects the life of maintenance strategies. However, the number of cars is not a key factor. The recognized factor that affects any treatment is indeed the effect of heavy traffic which is defined by the American Association of State Highway and Transportation Officials (AASHTO) as 18-kip equivalent single axle loads (ESAL’s). Caltrans uses the Traffic Index which can be easily converted into ESAL’s. Also, most structural analysis and reflective crack modelling programs require some input to calculate stress caused by actual loads derived from ESAL’s. Furthermore for treatment life to be meaningful, one must know the actual pavement condition at the time of the application of the treatment.

Since pavement preservation is considered non-structural treatment, these treatments should only be used on pavements with low deflection values and low levels of distress. If high deflections (beyond a certain limit) are present, rehabilitation of the pavement will be needed. There is also a maximum cracking threshold before a certain treatment is applied. For pavement preservation, it is suggested that a maximum value of 5% cracking and a minimum Pavement Condition Index of 70 (ASTM 2010) be used as the limits for applying pavement preservation treatments. If the pavement is in poor condition, it may have structural problems. Therefore, pavement preservation should not be used as an option in these situations. Preventive maintenance treatments are not cost effective in the late cycle of pavement life. When determining extended life benefits, it can be shown that placing some pavement preservation treatments on pavements in poor condition is not cost effective.

In summary, the primary concern for preservation treatments is surface cracking or ravelling when the pavement is in good to medium condition; and structural cracking when the pavement is in poor condition. It could be either reflective or structural cracking in the medium condition. It should be noted that this study focuses mainly on the benefits of maintenance treatments due to their prevention of moisture intrusion through existing cracks, and does not address the other benefits that are associated of mitigating other types of distress such as ravelling or bleeding. Pavement preservation should preserve the structural integrity of the pavement so that it can perform for a longer time where structural integrity implies load carrying capacity of the pavement. For example, crack sealing may provide the benefits of minimizing water intrusion into the base and subgrade and prevent fines from accumulating in the crack. Treatment life is defined as the number of years a given treatment will serve its function (before another treatment is required). Treatment life is a function of the existing pavement condition and other factors such as traffic, climate, quality of materials and construction.

3 INTRINSIC MAINTENANCE MATERIAL PROPERTIES

It was felt that there was a need to present, in a simple format, a summary of the data of the key aspects that contribute to what is intrinsically valuable in a treatment. Generically, it can be considered that many aspects will or may contribute to the quality and durability of a flexible pavement treatment such as the following:

- Quantity of binder,
- Aging characteristics of the binder used in treatments,
- Elastic characteristics of binder,
- Strain energy at break of the binder,
- Types of additives (none, polymer, rubber, others),
- Mix stiffness (if applicable).

A preliminary summary research allowed the determination of the effective binder content available for each of the treatment. The average values of the amounts of binder were used in the treatments; while for emulsions the residual binder content was used. It was also considered the use of tack coats add to the binder content available to each treatment. Clearly one important aspect is also thickness of the treatment as it provides some indication of the degree of protection the treatment provides to the underlying layer and to itself. The data was derived from the following treatments: Hot mix asphalt (HMA) Crack sealing, HMA Crack filling, Fog seals, Rejuvenator seals, Scrub seals, Slurry seals, rubberized emulsion aggregate slurry (REAS) seal, Micro-Surfacing, polymer modified emulsion (PME) chip seals, polymer modified asphalt (PMA) chip seals, asphalt rubber (AR) chip seals, Cape seals AR (slurry) 12.5 mm, Cape seals AR (micro) 19mm and Conventional HMA. Numerous 25 mm, surfacing were also including open graded asphalt concrete (OGAC), polymer based asphalt (PBA) HMA, rubberized asphalt concrete-gap graded (RAC-G), rubberized asphalt concrete-open graded (RAC-O), rubberized asphalt concrete open graded [RAC-O (HB)], and bonded wearing course-open graded (BWC-Open). 19 mm, surfacing including bonded wearing course-gap graded (BWC-Gap), BWC-RAC-G, BWC-RAC-O and open graded.

Several types of binder are available for use in the various treatments. The quality of binder has been defined many different ways, such as resistance to aging, elastic recovery, stiffness and other. Clearly aging resistance is an important aspect, but specifications today are such that all binders show similar values by aging in the Rolling Thin Film Oven (RTFO) and Pressure Aging Vessel (PAV). One key aspect contributing to the longevity of a surface treatment, beyond binder quantity, is its capability to withstand strain before breaking. Limited data are available for many binders regarding the strain energy at the break point (Kaloush 2002 and 2003), (Zborowski 2006) and as such the conclusions and numbers included in this section should be revised as more data are collected. However, these noted reports contain data comparing the strain energy at the breaking point for asphalt rubber (AR) binder and conventional binders. Also, relating this information to the fact that AR is known to withstand 5 times the strain (Green 1977) before breaking, and the results of four point flexural fatigue tests where usually the ratio between fatigue life at the same strain level is 1 to 10 between conventional and AR binder mixes and 1 to 3 for polymer modified mixes in this study (Sousa et al, 2000; Sousa et al, 2003 and Sousa et al, 2006), the following ratios were adopted as shown in Table 1 (again subject to further analysis).

Table 1. *Ratios of Strain Energy at Break*

Binder type	Ratio of strain energy at break of mixes (or binder)
Conventional	1
Polymer/Other Modified Binder	1.5
Asphalt Rubber	5

4 TREATMENT PERFORMANCE CAPACITY

To bring into a single parameter several of the key aspects related to the performance of a treatment in a previous report (Sousa and Way, 2007), the authors developed a conceptual measure of treatment effectiveness called the Treatment Performance Capacity (TPC) and it is defined as follows:

$$TPC = BC \times SE \times T \qquad [2]$$

where: TPC = Treatment Performance Capacity;
BC = Binder Content per unit area (L/m^2);
SE = Strain Energy at failure ratio;
T = Thickness of treatment (mm).

Obviously a fog seal with a regular emulsion will have a much smaller number in terms of TPC than a chip seal simply because it has less binder. Also an asphalt rubber treatment will show a better capacity number (even if with the same binder content) because has a higher strain energy at failure than regular binder. The concept that this index is aimed at capturing is simple: more binder is better; better binder is also better; but this factor may be compounded or confounded (possible bleeding or flushing and low skid resistance value) with more binder which also promotes less aging. A treatment with a large TPC value, when placed under heavy traffic over a badly cracked pavement will have its performance capacity consumed, “drained”, faster compared to when it is placed over a low traffic non-cracked pavement. Obviously a treatment with a low TPC value will have its performance capacity consumed even faster under the same scenarios. The TPC is inherent to each treatment. How long it takes to “consume” that capacity depends on the cracking condition, traffic and climate where the treatment is applied.

5 MODELLING THE GENERAL EFFECT OF TPC ON TREATMENT LIFE

From the analysis of the data presented an example of the model is shown in Figure 1 for Coastal and Valley region. It can be observed that the effect of TPC appears to drive the life of a pavement preservation treatment. For a given set of conditions, treatments with higher TPC appear to outperform in general those with lower TPC.

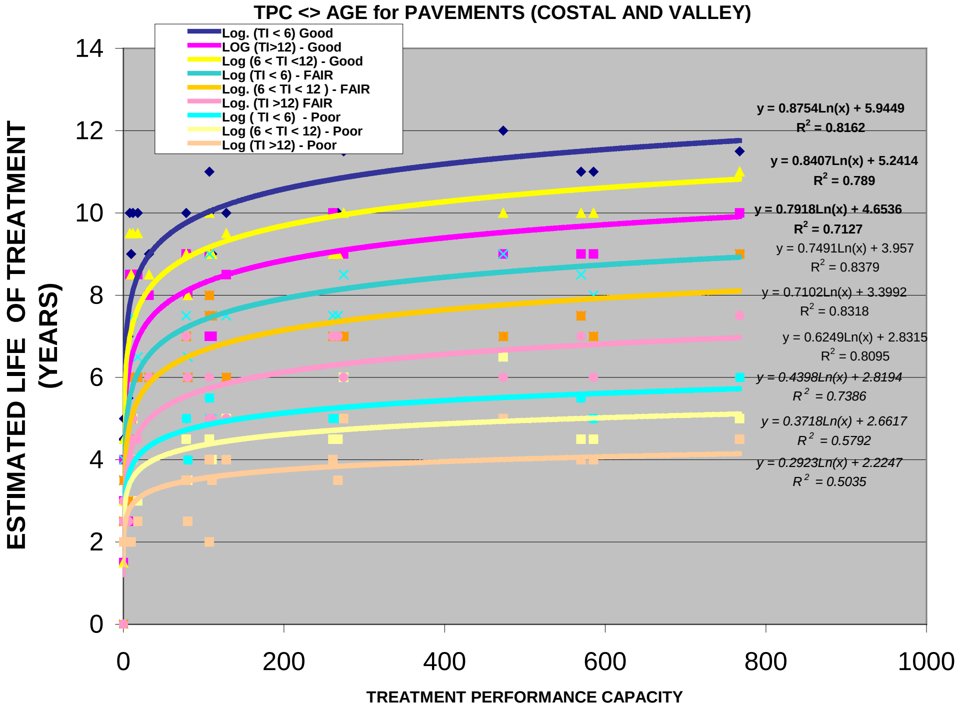


Figure 1. *Influence of TPC on Treatment Life for Coastal and Valley Regions*

Treatment life is also strongly affected by environment. After several trials, it was determined that the temperature that best explained the observed effect was the difference between the weighted mean monthly air temperature (Shell 1985) and the minimum air temperature. The statistical analysis used to develop the model to fit the treatment life results was performed using the nonlinear estimation option of the IBM® SPSS® Statistics software. This option allows the user to define a specified regression equation which is fitted to the existing data. The use of a suitable estimation method, in the case the Levenberg-Marquardt estimation method produced a precise estimation of the model parameters (Levenberg 1944; Marquardt 1963). A general model was developed using the subjective lives and all other available objective data, i.e. calculated corresponding TPC to estimate the subjective lives by a rational model. The following equations provide the best fit of Treatment Life (LIFE) of a given pavement condition with the TPC by a logarithmic equation:

$$LIFE = k_1 \times \log(TPC) + k_2 \qquad [3]$$

where: LIFE = Treatment Life;
TPC = Treatment Performance Capacity;
k_1 and k_2 = Coefficients.

The inclusion of the other independent variables (Reflective Cracking Temperature (RCT), Percent Cracking (PC), and Traffic Index (TI), is applied in the k_1 and k_2 coefficients of the logarithmic equation.

Thus, the difficult job of this task is selection of the equations that best define the influence of Reflective Cracking Temperature (RCT), Percent Cracking (PC), and Traffic Index (TI) in the logarithmic equation. Among the known equations, a parabolic regression seems to be best at producing a fit of the existing data, resulting in the model expressed in Equations 4 and 5,

$$k_1 = \prod_{i=1}^{3} \left(a_{i1} + a_{i2} \times X_i + a_{i3} \times X_i^2 \right) \qquad [4]$$

$$k_2 = \prod_{i=1}^{3} \left(\mathrm{b}_{i1} + \mathrm{b}_{i2} \times X_i + \mathrm{b}_{i3} \times X_i^2 \right) \qquad [5]$$

where: aij and bij = coefficients given in Table 2;
X_i = Variables defined in Table 3.

Table 2. *Statistical coefficients for the life model (Equations 2 and 3) [R2=0.84]*

i	a_{i1}	a_{i2}	a_{i1}	b_{i2}	b_{i3}	b_{i3}
1 RCT	-1.029E+02	3.826E+00	-5.381E-02	-1.269E+02	-8.601E-01	3.199E-02
2 PC	3.223E-02	-1.646E-03	3.354E-05	-8.063E-01	6.716E-02	-2.350E-03
3 TI	-1.708E+00	9.926E-03	1.342E-03	7.147E-02	-3.076E-03	7.195E-05

Table 3. *Variables defining the pavement conditions in Equations 4 and 5*

i	X_I	*Minimum*	*Maximum*
1	RCT - Temperature defined by: Air Mean Monthly – Minimum Air (^{o}C)	20	45
2	PC – Percent Cracking	0	18
3	TI – Traffic Index	3	15

All variables show statistical significance and a remarkably good R2 correlation of the model of 0.84 as shown in Figure 2.

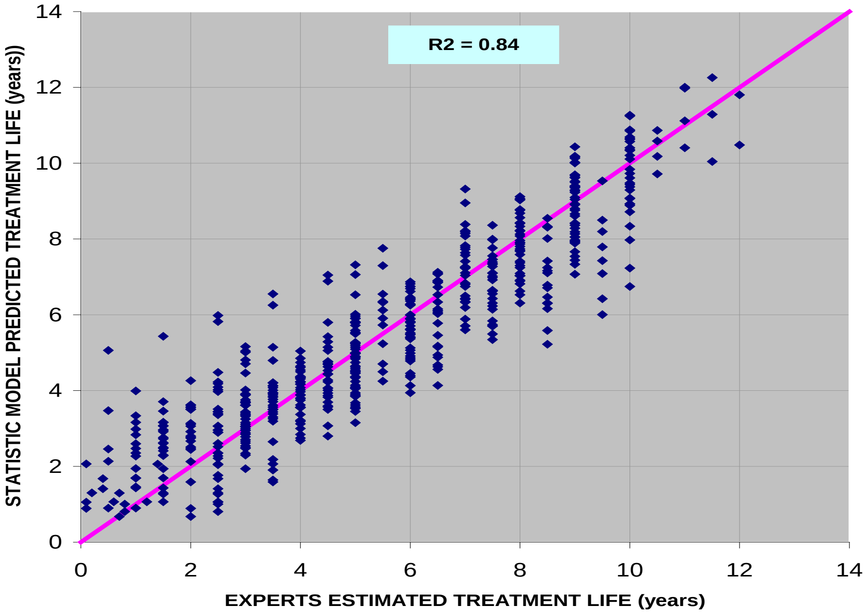


Figure 2. *Best fit between expert estimated treatment life and corresponding estimations from statistical model*

6 COST-EFFECTIVENESS OF TREATMENT ALTERNATIVES

Cost-effectiveness is defined in this report as a measure of the cost of the treatment in relation to its performance. Given that each treatment has a TPC; it is possible to couple this with the cost of the treatments and determine the cost effectiveness of each treatment. It has already been determined that there is a very good correlation (at times higher then 80%) between the TPC and expected treatment lives. Based on the above information, the cost-effectiveness (TPC/$) of each treatment was determined by dividing the treatment's TPC by its cost. This is shown In Figure 3 where all of these values are compared for all treatments. It can be observed that there is a very wide range in the cost effectiveness of treatments. Some are as low as 0.25 while some are close to 70.

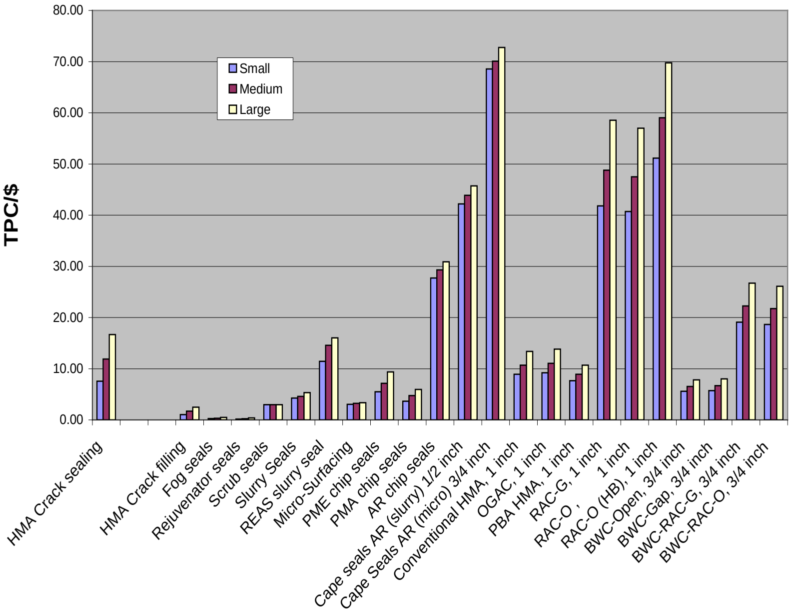


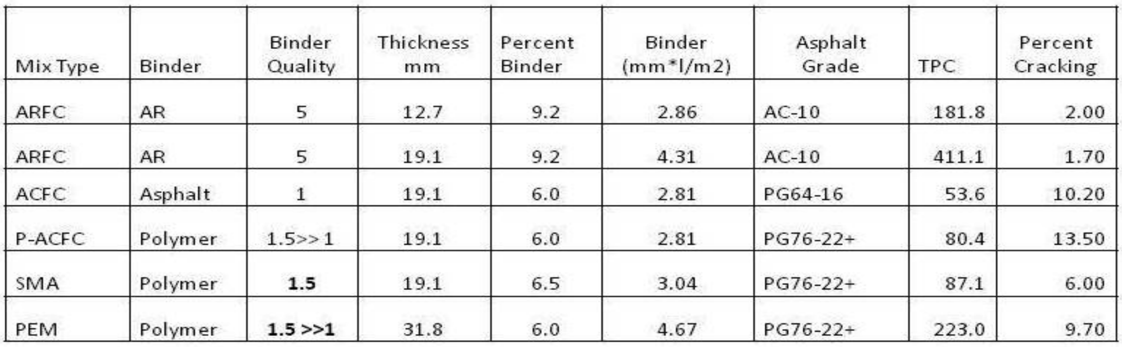
Figure 3. *Cost effectiveness, measured in TPC/$, for California treatments function of job size*

These values could be used as a criterion to help Road Departments select their maintenance strategies. What this data is basically suggesting is that treatments with low TPC/$ should only be used in very special situations. Otherwise, other treatments can be used that are more cost-effective. The data also indicates that generally the most cost-effective treatments follow the concept that, *"more binder is better; better binder is also better; and thicker treatment is better*" - in all cases in generic terms. Asphalt rubber products generally have the best TPC/$ because they fit the general concept and associated underlying qualities to resist cracking and water intrusion. Depending on what the current maintenance strategies it appears that by maximizing treatments with asphalt rubber, the potential for long term savings or increase pavement performance is very high. A road department can either decrease its budgetary needs or increase the overall level of the quality of the network by selecting mainly solutions with high TPC/$ ratios.

7 OTHER EXAMPLES THAT SUPPORT THE TPC CONCEPT

To investigate to what extent the TPC concept is robust two studies were selected to develop a correlation between some level of performance (i.e. percent cracking) and TPC. One study was based on several test sections built on Arizona Interstate I-10 initially constructed to evaluate the noise levels of several types of overlay mixes. In the late 1990's the ADOT developed a state-wide wearing course experiment and constructed a major test section on Interstate 10 about 60 km south of Phoenix, Arizona. The experiment was designed to evaluate five wearing courses over a 12 - 15 year period. The five wearing courses evaluated: Permeable European Mixture (PEM), Stone Matrix Asphalt (SMA), Asphalt Rubber Open Graded Friction Course, Polymer Modified Open Graded Friction Course and an Open Graded Friction Course without binder modification. The test sections were placed in replicates and randomized (Carlson 2009). This was done to ensure there was little to no bias in the test results. The key aspect of the mix properties and performance are presented in Table 4. Figure 4 shows the correlation of percent cracking and TPC. A correlation of 0.67 was obtained between TPC and percent cracking after adjusting the "Binder Quality" from 1.5 to 1. This is consistent with the findings in the AR2009 paper (Carlson 2009) which indicated that in desert environments low polymer binder contents tend, in the long run, to behave similarly to asphalt binder without modification.

Table 4 - I-10 Wearing Course Test Section TPC and Percent Cracking after 11 years of Service



Mix Type	Binder	Binder Quality	Thickness mm	Percent Binder	Binder (mm*l/m2)	Asphalt Grade	TPC	Percent Cracking
ARFC	AR	5	12.7	9.2	2.86	AC-10	181.8	2.00
ARFC	AR	5	19.1	9.2	4.31	AC-10	411.1	1.70
ACFC	Asphalt	1	19.1	6.0	2.81	PG64-16	53.6	10.20
P-ACFC	Polymer	1.5>>1	19.1	6.0	2.81	PG76-22+	80.4	13.50
SMA	Polymer	**1.5**	19.1	6.5	3.04	PG76-22+	87.1	6.00
PEM	Polymer	**1.5 >>1**	31.8	6.0	4.67	PG76-22+	223.0	9.70

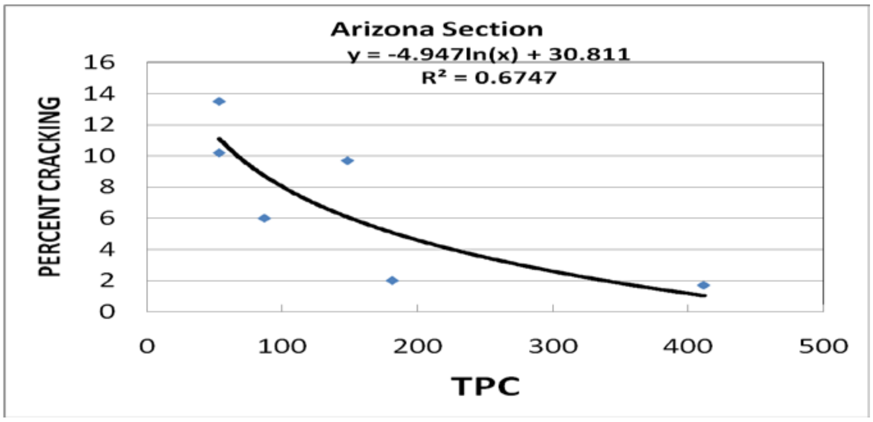
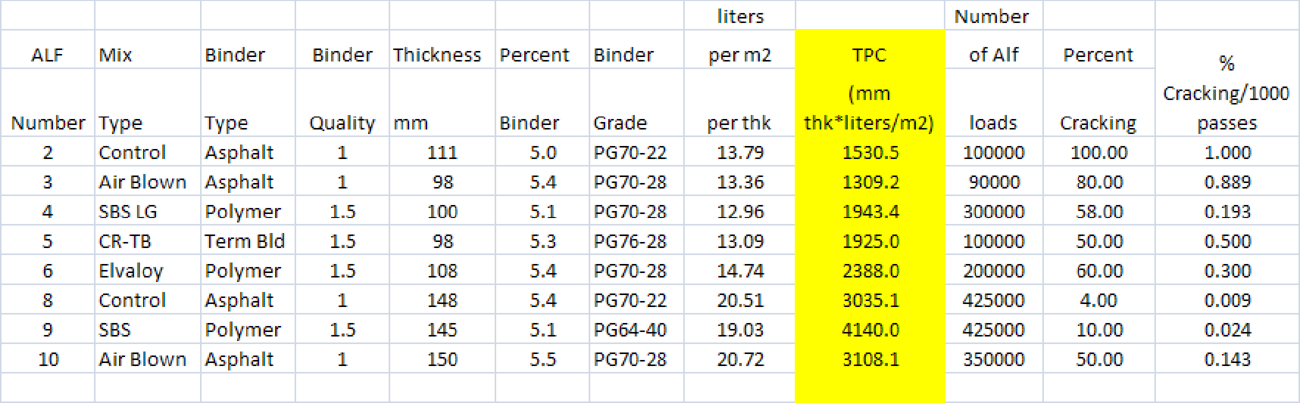


Figure 4. Arizona Test Section Percent Cracking versus TPC

Another well documented study was used to further push the boundaries of the TPC concept. In the ALF study sections 10 and 15 cm thick were built under similar base and subbase sections (Qi 2006 and Qi 2008). To harmonize the results it was decided to evaluate only those sections that did exhibit cracking. The key parameters are presented in Table 5.

Table 5 - TPC values from the ALF study



ALF Number	Mix Type	Binder Type	Binder Quality	Thickness mm	Percent Binder	Binder Grade	liters per m2 per thk	TPC (mm thk*liters/m2)	Number of Alf loads	Percent Cracking	% Cracking/1000 passes
2	Control	Asphalt	1	111	5.0	PG70-22	13.79	1530.5	100000	100.00	1.000
3	Air Blown	Asphalt	1	98	5.4	PG70-28	13.36	1309.2	90000	80.00	0.889
4	SBS LG	Polymer	1.5	100	5.1	PG70-28	12.96	1943.4	300000	58.00	0.193
5	CR-TB	Term Bld	1.5	98	5.3	PG76-28	13.09	1925.0	100000	50.00	0.500
6	Elvaloy	Polymer	1.5	108	5.4	PG70-28	14.74	2388.0	200000	60.00	0.300
8	Control	Asphalt	1	148	5.4	PG70-22	20.51	3035.1	425000	4.00	0.009
9	SBS	Polymer	1.5	145	5.1	PG64-40	19.03	4140.0	425000	10.00	0.024
10	Air Blown	Asphalt	1	150	5.5	PG70-28	20.72	3108.1	350000	50.00	0.143

The results indicate shown on Figure 5 show that the TPC has a R2 correlation of 0.72 with rate of cracking which is actually surprising that such a simple concept can capture 70% of the performance taking into consideration the two different section thickness, binder contents and binder types.

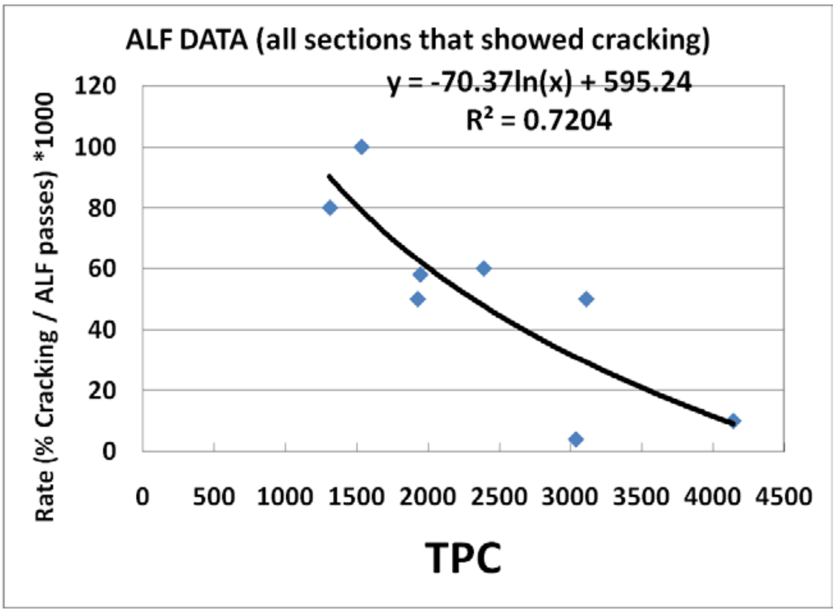


Figure 5. ALF Test Section Percent Cracking versus TPC

8 CONCLUSIONS

This research introduces the concept Treatment Performance Capacity (TPC). The observations correlating the TPC of a treatment or overlay with it's performance indicate, (what is intuitively known) that preservation treatments perform better if they have more binder, are made of a better binder and are thicker (i.e. more long lasting and more waterproof).

A model was developed to relate treatment life function in terms of TPC, pavement condition, traffic level and location temperatures (actually only the reflective cracking temperature given by the difference between the Shell mean weighted average temperature and the lowest temperature representative of each climatic region), for several asphalt based treatments. This model was able to explain the performance of 23 treatments, in 3 climatic zones, three pavement conditions levels and three traffic magnitudes (i.e. 621 observations), with only 4 variables, with a remarkably high correlation R^2 of 0.84.

This concept was further extended to thin wearing courses in actual road segments in Arizona and also in thin and thick pavement sections on the ALF study. The correlations between observed performance and TPC were all around 70%, which further validate the concept.

Using the TPC values for each treatment and the price of each treatment a cost effectiveness table for all treatments was developed (by simply dividing the TPC of a treatment by its cost per square yard) using data from California. The results indicate that using the TPC analysis, road departments would be able to improve the performance on their networks by selecting preservation solutions with the highest TPC/$ ratio.

8 ACKNOWLEDGMENT

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9 DISCLAIMER

The contents of this report reflect the only the views of the authors. The authors do not endorse specific products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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