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# Using MEPDG to Develop Rational Pay Factor for Hot Mix Asphalt Construction

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***Abstract:*** *Most highway agencies are using subjective measures to rate the quality of construction projects. The main purposes of rating the contractor performance are for qualification, bidding, or payment schedules. The pay factor (PF) can be defined as a multiplication factor that is often used to determine the contractor pay for the unit of work. The objective of this paper is to propose a rational methodology for defining PF based on basic understanding of the effect of different hot mix asphalt parameters on pavement life. Mechanistic-Empirical Pavement Design Guide (MEPDG) software is used to find the effect of different variables on pavement life. Three main factors considered in pay factor equation for their effect on pavement life:air voids, asphalt content, and percent passing sieve # 200 (P200). The pavement lifebased on the fatigue and rutting failure criteriaare used in the PF model to reflect actual contractor performance.The developed PF model was implemented on a case study.*
***Keywords:*** *Pay Factor; MEPDG;Highway;Fatigue; Rutting; Pavement Life*

## I. Introduction

The current practice in the pavement industry uses the pay factor (PF) in adjusting the contractor pay, based on the percentage of work that falls within the specified limits. Agencies have developed their own equations to reward or penalize the contractor, using the pay factor. Using the pay factor assumes that giving the contractor a fraction of the full pay would motivate improved performance.Several agencies have chosen to weigh the pay factors with the concept that some quality characteristics are more important than others. For example, when mixture properties and field compaction are used as quality characteristics, the in–place air voids are often weighted more heavily than the mixture properties (Burati, 2003).

PF is introduced in the current research since it is adopted by many agencies to reward or penalize contractors for their quality of work. PF is a multiplication factor used to determine the contractor pay for the unit of work. After the project or a project stage is completed, the owner/agency evaluates the product, and based on this evaluation, the contractor gets paid. The contractor could be paid in full, penalized, or rewarded, depending on the performance and the quality of the final product (TRB, 2005).

Weed (1998) proposed a method for developing pay schedules based on the need for a rational method to relate As-build quality to the expected performance and for use in the development of reliable and defensible pay schedules. This method is believed to reflect more accurately the value of failure to meet the design level of quality because the actions upon which any pay reduction is based are not a function of the thickness of the pavement layer or the bid price.

Weed (2000) offered a method for combining the effects of multiple deficiencies.

A rational and feasible method for quantitatively calculating pay factors was described by Monismith et al. (2004) for asphalt construction. This method used results of tests on the Caltrans Heavy Vehicle Simulator and the WesTrach accelerated pavement performance test program in the development of performance models for fatigue and Rutting. Whiteley et al. (2005) developed a method for generating pay factors based on the Life Cycle Cost (LCC).The quality of hot mix asphalt (HMA) is dependent on several materials and construction factors. Several quality tests are performed on site and/or in the laboratory as part of the quality control/assurance processes. Three main pavement quality characteristics were considered in model development in the literature: asphalt content (AC), air voids (AV), and percentage passing sieve # 200 (P200) (Elyamany and Abdelrahman (2010); Elyamany et. al (2013)).

## II. Quality Measures

The results of quality testing are transformed to percent defective (PD) as a quality measure that indicates how far the contractor from the specification limits. Percent defective has been preferred in recent years because it simultaneously measures both the average and the variability level in a statistically efficient way. PD can be calculated using another quality measure, i.e., the Percent within Limits (PWL). It is related to PWL by the simple relationship, PD = 100 – PWL (Burati, 2003).

The use of PD as a quality measure has some advantages, particularly with two–sided specifications, because PD below the lower specification limit can simply be added to the PD above the upper specification limit to obtain the total PD value (Breakah 2007). PWL and PD are capable of combining more than one stochastic measure into one single number. Conceptually, the PWL procedure is based on the normal distribution features. The area under the normal curve can be calculated to determine the percentage of population that is within certain limits. Similarly, the percentage of the lot that is within the specification limits can be estimated. Detailed procedures used to calculate PWL and PD are presented in (Burati 2003).
PF is calculated using empirical equations suggested by the agency. Equation (1) is a linear equation that is widely recognized by many highway agencies (Burati, 2003).

$$PF = 55 + 0.5 \times PWL \quad (1)$$

This equation assumes the maximum and the minimum PF are 105 and 55 at 100PWL and 0PWL, respectively. Many practitioners and researchers suggest the Accepted Quality Limit (AQL) to be satisfied at 90PWL with a PF equal to 100. They also suggested the Rejected Quality Limit (RQL) to be satisfied at 50PWL with a PF equal to 80 (Burati, 2003). Equation (2) is studied as a non-linear PF equation proposed by another agency (Burati, 2003).

$$PF = 2.4 \times PWL - 0.01 \times PWL2 - 35 \quad (2)$$

This equation assumes the minimum and the maximum PF are 0 and 105 at 15.6PWL and 100PWL, respectively. Since the minimum PF of 0 is not rational, this equation should have a minimum PWL between 40 and 50 to keep the minimum PF between 45 and 60.

## III. Study Objectives

This paper aims to develop a methodology for rational determination of the parameters weights of the pay factor equations.The parameters weights would be calculated based on the impact of each parameter on flexible pavement performance/life. The Pavement Life would be evaluated using the Mechanistic-Empirical Pavement Design Guide (MEPDG).

## IV. Research Methodology

The goal of the research is to develop a rational pay factor model based on the effect of HMA parameters on pavement performance.The research methodology is presented in Figure 1. The effect of the HMA parameters on asphalt pavement rutting and alligator cracking was investigated using Mechanistic-Empirical Pavement Design Guide (MEPDG), Version 1.1. The MEPDG is the state of the art software developed by American Association of State Highway and Transportation Officials (AASHTO) to predict pavement distress over pavement life. The software uses a mechanistic-empirical approach to pavement design that combines features from both the mechanistic and empirical approaches. The mechanistic component is a mechanics-based determination of pavement responses (stresses and strains) due to loading and environmental influences. These responses are then related to the performance of the pavement via empirical distress models (transfer functions)(Huang 2004).

The change in the predicted pavement life at 90% reliability was used to present the impact of the change of HMA parameters on pavement life. The relative effect of these factors (AV, AC, and P200) on pavement life was used to develop the relative weights in the pay factor equation.

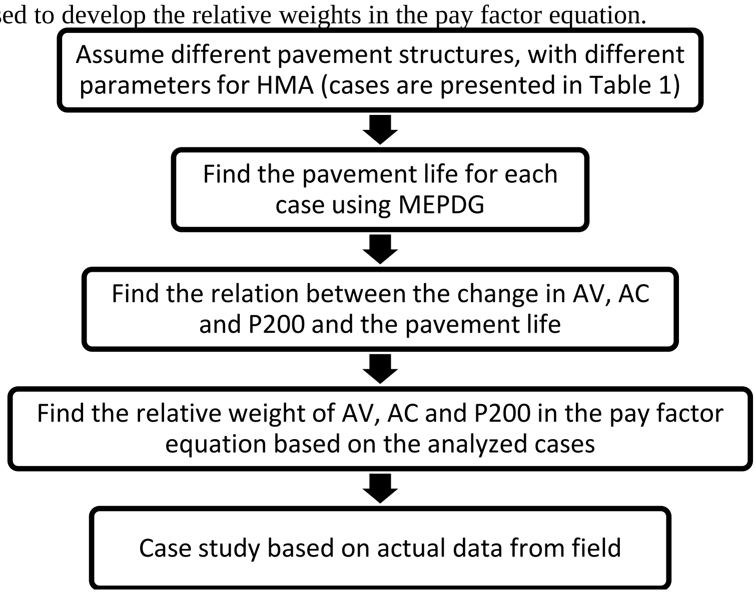



**Figure 1 Research Methodology**

## MEPDG Data

The main factors considered for their effect on pavement life and hence for inclusion in pay factor equation are:

- Air voids (AV): Air voids varied from 3% to 7% (3, 4, 5, 6 and 7%)
  The mix design literature indicates that in-place air voids of an asphalt mixture have an optimum value at which the minimum rutting will occur. When air voids fall below a threshold of 2 to 4%, plastic flow will occur. As the Design Guide model for AC rutting does not incorporate tertiary flow (plastic flow) consideration; this would limit the conclusion using MEPDG to air voids level greater than 3% which was done during this research
- Asphalt content (AC): the asphalt content varied from 8 to 13% by total volume of the mix (8, 9, 10, 11, 12 and 13%)
- Percent passing # 200 (P200): it varied from 2 to 10% of the aggregate weight (2, 7 and 10 %). These values were selected to cover typical range for dust content in HMA for Egyptian Specification (GARBLT 1998).

The other input data used in MEPDG are shown in Table 1

**Table 1 Variable Used in MEPDG**

| **Parameter** | **Variables** | **Values** | **Source of Data** |
|---|---|---|---|
| Traffic | Traffic volume AADTT (vehicle/day) | 1000 (medium traffic)[a]<br>7000 (high traffic)[b] | (Appendix GG-2) |
| HMA | Air voids | 3, 4, 5 ,6, 7% | |
| | Effective Binder content | 8, 9, 10, 11, 12, 13% | |
| | % Passing # 200, % | 2, 7, 10 | |
| | Thickness [g] | 2 in<br>6 in | The 2 in was analyzed only for the medium traffic |
| MEPDG data input for all analyzed cases | | | |
| Traffic | Other Traffic Parameters | Default MEPDG level 3 | |
| Climate | Location | Austin Texas | |
| | GWT height | 12 ft | |
| HMA | Total unit weight (Ppf) | 150 | Medium mix (Appendix GG-2, Attia and Abdelraman 2010) |
| | % Retained ¾” | 11 | |
| | % Retained 3/8” | 35 | |
| | % Retained # 4 | 52 | |
| | PG Grade | 76-22 | |
| | Other HMA parameters | Default MEPDG level 3 | |
| Base | $M_R$ | 29500 | Typical A-1-a base layer modulus value in MEPDG |
| | Thickness | 12 in | Selected typical value |
| Subgrade | $M_R$ | 15000 psi | Medium subgrade support (Appendix GG-2) |
| | PI | 16 | |

[a]Medium traffic will be used with thin HMA section (i.e. HMA = 2 in)
[b] high traffic will be used with thick HMA section (i.e. HMA =6 in)
[g]Arbitrary selected thicknesses to present thin and thick AC layer
AADTT: average annual daily truck traffic, HMA: hot mix asphalt layer
GWT: ground water table height from pavement surface

## V. Performance Indicators

Fatigue (Fat) and Rutting (Rut),are the main distresses considered to affect HMA pavement in warm climate.A classic fatigue crack starts at the bottom of a HMA pavement layer (or structure) and grows towards the surface. Its development is directly proportional to the strain level at the bottom of the HMA layer (Carpenter, 2003). This strain level changes with HMA thickness (thicker pavements give lower strain values), stiffness and other properties.The primary functional distress for flexible pavements is permanent deformation known as rutting. Rutting (Rut) is the cumulative plastic or unrecoverable strain under loading and occurs from mix design deficiencies, construction, layer thickness selection, and material quality of sublayers. (Roperts et. al, 1996, Shahin 2005).

The failure criteria used in this research are: alligator cracking exceeding 18% of the area, or total rutting exceeding 0.75 inches, at the reliability level. Fatigue failure criterion was selected following Huang (2004). It was reported the determining the number of load repetition to failure based on fatigue cracking for flexible pavement following the asphalt institute method resulted in 20% fatigue cracking in the total area as observed on AASHO Road test (Huang, 2004). Some of the sections under comparison in this study did not reach the 20% fatigue after 20 years (analysis period used in the MEPDG) at the reliability level. So the failure criterion was reduced to 18% to enable comparing different pavement sections behavior without extrapolating the MEPDG results. The rutting criterion was selected to be Total rutting exceeds 0.75 inches. This failure criterion was the default total rutting in the MEPDG. This failure criterion was also very similar to the Shell permanent deformation failure criterion of 0.7 in (Huang, 2004).

Figure 2 Shows sample of the output result from the MEPDG. The software result indicates the distress (in this case rutting) over pavement life. The life of each case is then defined based on the pre-selected failure criterion, as presented in figure 2.

Reference case for the analysis to evaluate the effect of the mix parameters on pavement life was: asphalt content (AC) =11% by volume of mix, air voids (AV) = 5%, percent passing #200 (P200) = 7%.

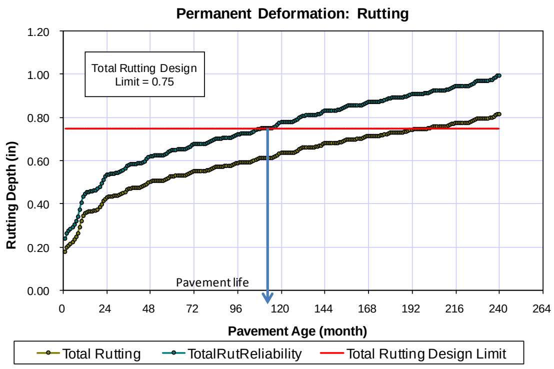



**Figure 2 Relation between pavement life and permanent deformation**

The MEPDG software is run for 48 different scenarios for 2in thick pavement and another 48 different scenarios for 6in thick pavement. The results of theMEPDG software runs are fatigue and rutting over the pavement life. A base value of pavement life is chosen for each performance indicator. Pavement life for each scenario is divided by the pavement life of the base value. This ratio is considered as the dependent variable in a regression equation with the ratio between the case value and base value of the quality characteristics as the independent variables. Equation (3) and (4) represent the general form of the regression equation.

$$\Delta L_{Rut} = C1 + C2 * \Delta AC + C3 * \Delta AV + C4 * \Delta P200 \quad (3)$$

$$\Delta L_{Fat} = C5 + C6 * \Delta AC + C7 * \Delta AV + C8 * \Delta P200 \quad (4)$$

Where; C1, C2, C3, C4, C5, C6, C7, and C8 are regression coefficients,$\Delta L_{Rut}$ is the ratio between the case value and base value for rutting life, $\Delta L_{Fat}$ is the ratio between the case value and base value for fatigue life, $\Delta AC$ is the ratio between the case value and base value for asphalt content, $\Delta AV$ is the ratio between the case value and base value forair void, and $\Delta P200$ is the ratio between the case value and base value for percent passing sieve #200.

## VI. Results andAnalysis

Table 2 shows Fatigue life for all cases with thin layer of HMA (HMA = 2in thickness).

The base value of pavement life is chosen for each performance indicator as shown in Table 3.

Table 4 shows the regression model statistics for pavement life. Four models are available; all have R-square greater than 0.8.

**Table 2 Fatigue life for HMA 2in**

| | AC=10% | | | AC=11% | | | AC=12% | | | AC=13% | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AV | P200 =2% | P200 =7% | P200 =10% | P200 =2% | P200 =7% | P200 =10% | P200 =2% | P200 =7% | P200 =10% | P200 =2% | P200 =7% | P200 =10% |
| 3% | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 4% | 18.17 | 19 | 19 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 5% | 11.83 | 12.5 | 12.5 | 14.17 | **14.83** | 14.83 | 16.5 | 17.17 | 17.17 | 18.67 | 19.42 | 19.33 |
| 6% | 8 | 8.5 | 8.5 | 9.75 | 10.08 | 10.08 | 11.5 | 11.92 | 11.92 | 13.25 | 13.92 | 13.92 |

**Table 3 Base Value of Pavement Life**

| | Pavement Thickness | |
|---|---|---|
| | 2in | 6in |
| Fatigue Life | 14.83 | 11 |
| Rutting Life | 6 | 7.5 |

**Table 4 Regression Model for Pavement Life**

| Regression Statistics | | Fatigue life | Rutting life | Fatigue life | Rutting Life |
|---|---|---|---|---|---|
| | | 2 in | | 6 in | |
| Multiple R | | 0.918 | 0.946 | 0.953 | 0.932 |
| R Sq. | | 0.843 | 0.896 | 0.909 | 0.869 |
| Adjusted R Sq. | | 0.832 | 0.889 | 0.903 | 0.860 |
| Standard Error | | 0.112 | 0.031 | 0.116 | 0.089 |
| Coefficients | Intercept | 1.177 | 1.236 | 1.605 | 2.129 |
| | ΔAV | -1.048 | -0.256 | -1.546 | -0.576 |
| | ΔAC | 0.828 | -0.073 | 0.668 | -0.762 |
| | ΔP200 | 0.021 | 0.075 | 0.047 | 0.341 |

Number of observation = 48 for each HMA thickness (2 inches and 6 inches)

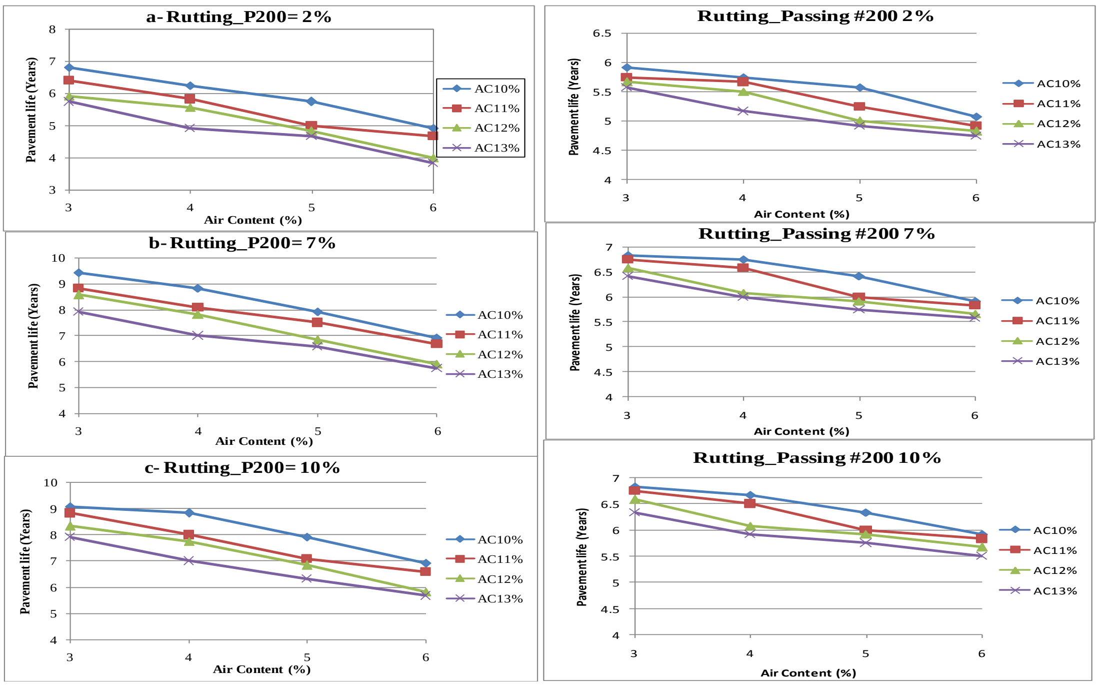
Figures 3.a and 3.b show that increasing air content or asphalt content cause clear reduction in pavement life based on rutting criterion, for both thin and thick (2 in or 6 in ) HMA pavement. This was clear also in the values of the regression coefficients presented in Table 4. From Table 4, it can be seen that C2 and C3 in Equation 3 are negative values for both thin and thick HMA. Also looking at the values of C2 and C3 it can be concluded that the relative effect of air voids compared to AC would depend on the thickness of HMA layer.

Although the increaseof P200 from 2 to 7 % caused an increase in the pavement life, increasing P200 from 7 to 10% did not have an impact of the pavement life. Table 4 shows that the effect of P200 (Coefficient C4) is positive on rutting , and it is almost the opposite effect of AC. Figures 3.a and 3.b show that the variation in pavement life can reach up to 33% of pavement life due to the variation of AC content or the AV of the mix, based on rutting criterion. This agrees with expected behavior of HMA, as increasing fine content would cause the mix to be stiffer, while increasing AC or AV would cause the mix to be more susceptible to rutting.

Figure 4.a and 4.b shows that increasing air content or reducing asphalt content cause clear reduction in pavement life based on fatigue criterion, for both thin and thick (2 in or 6 in ) HMA. The increase of P200 from 2 to 10 % for both thin and thick HMA did not have an impact on the pavement life.

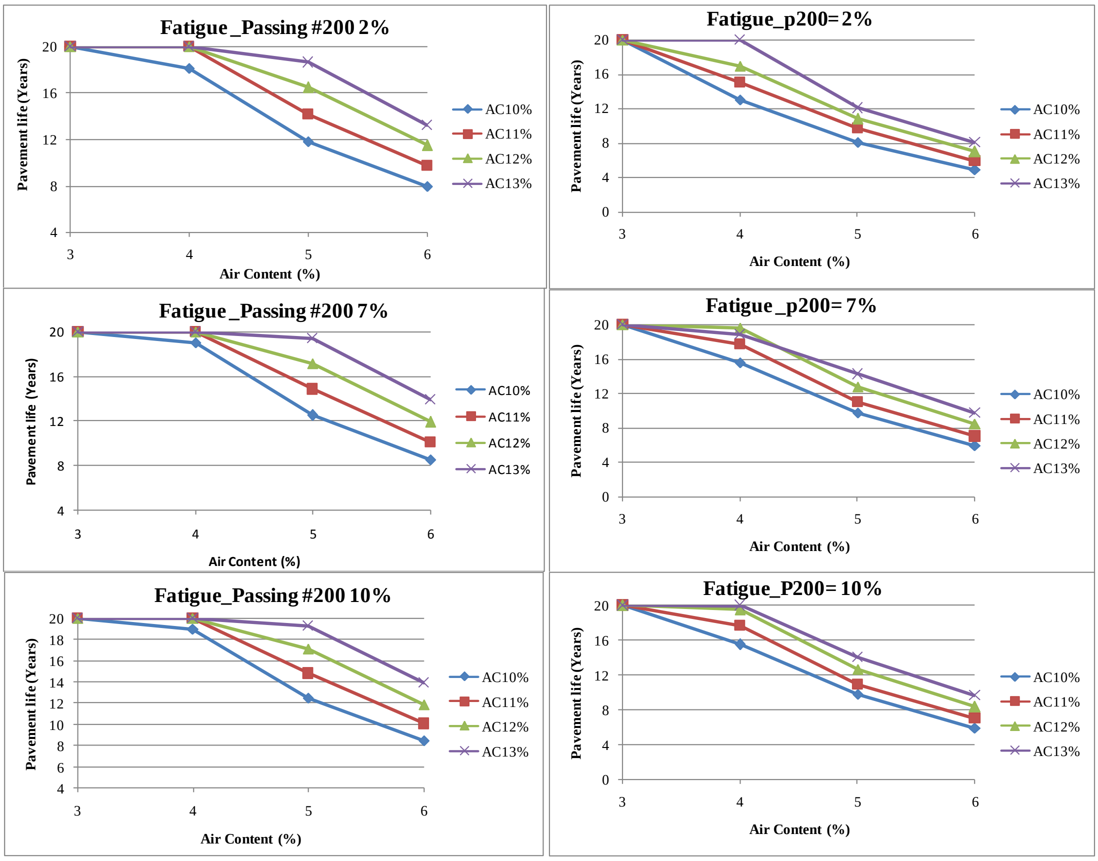
Figure 4.a shows that the variation in pavement life can reach up to 60% of pavement life due to the variation of AC content or the AV of the mix, based on fatigue criterion for thick HMA sections. Figure 4.b shows that the variation in pavement life can reach up to 80% of pavement life due to the variation of AC content or the AV of the mix, based on fatigue criterion for thin HMA sections.

Table 4 shows clearly that the coefficient C6 (of Equation 4) ispositive, reflecting the increase of pavement life for increasing asphalt content.Table 4 also shows that C 7 is negative, reflecting that increasing air voids would cause reduction in pavement life. The Coefficient C8 is too small, reflecting that the impact of P200 on pavement life is too small compared to the other two factors (AV and AC) based on Fatigue criteria.




**(a)** **(b)**

**Figure 3 Effect of AV, AC and P200 on pavement life based on rutting; a) 6 in HMA b) 2 in HMA**




**(a)** **(b)**

**Figure 4 Effect of AV, AC and P200 on pavement life based on Fatigue; a) 2 in HMA,6in HMA**

## Pay Factor Model Development

As previously mentioned, pay factor is believed to reflect more accurately the value of failure to meet the design level of quality. A Pay Factor Modelbased on pavement life is proposed using the MEPDG software. Figure 5 shows the process followed to develop the PF model.

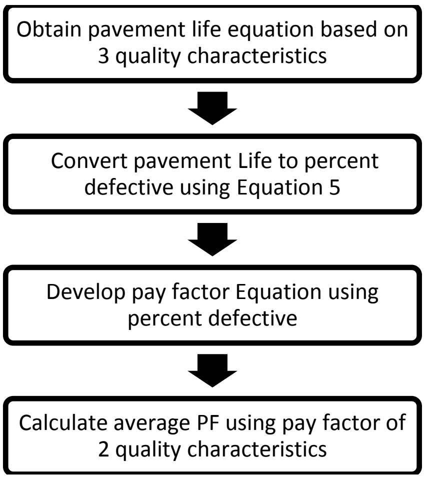



**Figure 5 Pay Factor Model Process**

## Percent Defective

Since, there is a lack of PF equations based on pavement life, conversion from pavement life to percent defective is important. Figure 6 shows the pavement life and percent defective relationship and Equation (5) represent it in general form. Equation (6) and (7) represent PD equation for rutting and fatigue.

$PD_x = 100 * (L_{max} – L_x) / (L_{max} – L_{min})$ (5)

$PD_{Rut} = 100 * (L_{Rutmax} – L_{Rut}) / (L_{Rutmax} – L_{Rutmin})$ (6)

$PD_{Fat} = 100 * (L_{Fatmax} – L_{Fat}) / (L_{Fatmax} – L_{Fatmin})$ (7)

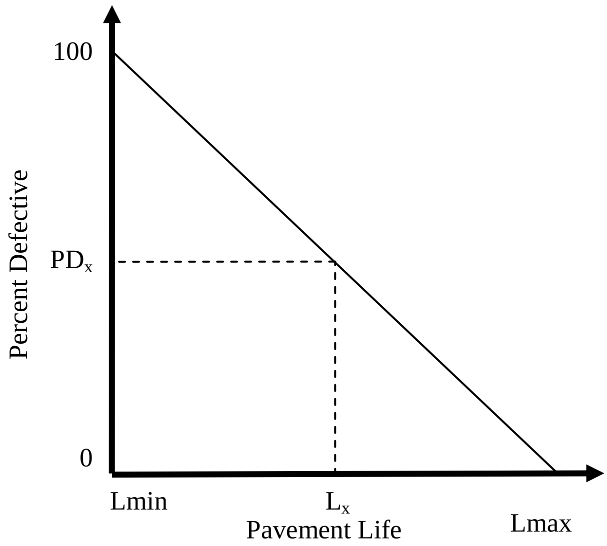



**Figure 6 Pavement Life and Percent Defective relationship**

## Pay Factor

The next step in developing the PF model is to use the linear PF relationship shown in Equation (1) for both performance indicators.

$PF_{Rut} = 105 - 0.5 \times PD_{Rut}$ (8)

$PF_{Fat} = 105 - 0.5 \times PD_{Fat}$ (9)

Where; $PD_{Rut}$ is percent defective for rutting, $PD_{Fat}$ is percent defective for fatigue, $PF_{Rut}$ is pay factor for rutting, and $PF_{Fat}$is pay factor for fatigue.

## Combined Pay Factor

Various agencies have considered at least four different approaches for combining a number of payment factors for individual acceptance quality characteristics into a single composite payment factor. These approaches include (Burati, 2003):

- Using the minimum individual payment factor.
- Averaging (possibly with weighting factors) the individual payment factors.
- Multiplying the individual payment factors.
- Summing the individual payment adjustments.

The optimum method to combine multiple PF's is to consider the actual weight of each performance indicator in expecting the pavement life. For the current research, averaging individual PF's considered as the most widely and accepted method for combining pay factors. The

$PF_{Ave} = 1/2 *(PF_{Rut} + PF_{Fat})$ (10)

## Case Study

A case study for a hypothetical road project with 6in HMA overlay. The base case for AC, AV, and P200 equal 11%, 5%, and 7%, respectively. The base case for fatigue life and rutting life equal 11 and 7.5 years, respectively. Table 5 shows the calculation of pay factor for the case study.The result shows that the pay factor for fatigue was 82.9% and it was 74.38%for rutting with an average of 78.64% considering both the fatigue and rutting life of the pavement. The agency can select to judge the contractor PF based on only one of the distresses, take the lower of the two pay factors, or take the average.

**Table 5 Case Study Calculation**

| | Fatigue | | Rutting | |
|---|---|---|---|---|
| **Coefficients** | **Min** | **Max** | **Min** | **Max** |
| ΔAV | 1.200 | 0.600 | 1.2 | 0.6 |
| ΔAC | 1.182 | 0.909 | 1.182 | 0.909 |
| ΔP200 | 0.286 | 1.429 | 0.286 | 1.429 |
| ΔL | 0.553 | 1.354 | 0.634 | 1.579 |
| Lbase | 11 | | 7.5 | |
| Lcase= Lbase*ΔL | 6.09 | 14.89 | 4.75 | 11.84 |
| PD | 44.19 | | 61.25 | |
| PF | 82.90 | | 74.38 | |
| PFave | 78.64 | | | |

## VII. Conclusion

Most highway agencies are using subjective measures to rate the quality of construction projects. The main purposes of rating the contractor performance are for qualification, bidding, or payment schedules. The Pay Factor can be defined as a multiplication factor that is often used to determine the contractor pay for the unit of work. The objective of this paper is to propose a rational methodology for defining pay factor based on basic understanding of the effect of different hot mix asphalt parameters on pavement life.The MEPDG software is usedto develop an equation for pavement life. Different values for AC, AV, and P200 are used to predict the pavement life for indifferent cases using MEPDG. The MEPDG software is run for 96 different scenarios for 2in thick and 6in thick HMA pavement. The output of theMEPDG software runs are fatigue and rutting over the pavement life. The Pavement life was then evaluated based on selected failure criteria.The next step was converting the pavement life percent defective.The agency can select to judge the contractor PF based on only one of the distresses, take the lower of the two pay factors, or take the average.A case study for a road project with 6in HMA layer was used to show the implementation of the model.

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