

# Analysis of Regression-Based Models for Prediction of Depth Temperature of Asphalt Layers – A Review

Mohammad Sedighian-Fard<sup>1</sup>, Nader Solatifar<sup>2\*</sup>

<sup>1</sup>Department of Civil Engineering, Urmia University, Urmia, Iran

<sup>2</sup> Department of Civil Engineering, Urmia University, Urmia, Iran

## ABSTRACT

Due to the viscoelastic behavior of asphalt mixtures, depth temperature of asphalt layers is very important in structural evaluation of flexible pavements. Depth temperature could be measured directly in the field, or may be predicted using prediction models. This paper presents a comprehensive analysis of different twelve regression-based models for prediction of depth temperature of asphalt layers. With reference to the literature, required input parameters, sensitivity analysis, evaluation of prediction performance, as well as a comparison of goodness of these models were discussed. Furthermore, calibrated models for different local conditions were presented. This is due to the fact that the original models were usually developed in specific geographical regions and climatic conditions. Results show that the regression-based models have a good performance and high accuracy in predicting the depth temperature of asphalt layers. Among the investigated models, according to the variety of data (or parameters) used in the model development, performance, considering the effect of various parameters, BELLS model introduced as one of the best regression-based models for prediction of depth temperature of asphalt layers. The model developed by Solatifar et al. as a new version of BELLS model, showed very good accuracy for newly constructed pavements. In addition, with applying some modifications, it could be possible to use these models in different pavements and local conditions.

## KEYWORDS

Asphalt Pavement, Depth Temperature of Asphalt Layers, Temperature Predictive Models, Regression-Based Model, BELLS Model.

---

\* Corresponding Author: Email: n.solatifar@urmia.ac.ir

## 1. Introduction

The depth temperature of asphalt layers is one of the most significant factors in the analysis, design, and rehabilitation process of flexible pavements. By owning this temperature distribution, it is possible to determine the impacts of temperature on pavements, especially in overlay design and rehabilitation studies. The depth temperature predictive models as an alternative to field and laboratory measurements of this factor are low-cost, rapid, and simple methods to determine the depth temperature of asphalt layers [1]. In this study, a comprehensive analysis was conducted on the developed regression-based models for prediction of depth temperature of asphalt layers. Evaluation of model performance, investigating input variables, sensitivity analysis of model parameters, and finally local calibration of models for use in different conditions were also presented.

## 2. Regression-Based Depth Temperature Predictive Models of Asphalt Layers

Twelve developed regression-based depth temperature predictive models for asphalt layers were scrutinized in this paper. Investigated models include Ramadhan and Wahhab [2], Diefenderfer et al. [3, 4], Hassan et al. [5], Velasquez et al. [6], Tabatabai et al. [7], Gedafa et al. [8],

Islam et al. [9], Ariawan et al. [10], Albayati and Alani [11], Asefzadeh et al. [12], Lee et al. [13], and BELLS [14] models.

## 3. Input Variables of Models

One of the predominant parameters in selection of depth temperature predictive model is availability of input variables. Table 1 reports the required input variables of the developed models. As can be seen in this table, the developed models by Ramadhan and Wahhab [2] and Tabatabai et al. [7] have minimum and maximum number of input variables, respectively.

## 4. Sensitivity Analysis of Model Parameters

In the sensitivity analysis of developed models, different parameters have been introduced as the most significant factors in asphalt layer depth temperature variations. The air temperature is the most crucial parameter that affects the depth temperature of asphalt layers [2, 10, 13]. The temperature at the pavement surface and depths near the surface are highly sensitive to air temperature [5, 12, 15]. The mid-depth pavement temperature is prominently sensitive to the time of day when the air temperature is high [8]. Moreover, the effect of air humidity besides air temperature is remarkable [10].

**Table 1. Input variables of regression-based depth temperature predictive models**

Model	Input Variable												
	Air Temperature	Pavement Surface Temperature	Daily Minimum and Maximum Air	Previous Day Average Air	Wind Speed	Solar Radiation	Air Humidity	Ground Temperature	Time of day (Decimal Hours)	Level of Compaction	Bitumen Content	Bitumen Type	Depth from Pavement Surface
Ramadhan and Wahhab [2]	✓												✓
Diefenderfer et al. [3, 4]	✓					✓							✓
Hassan et al. [5]			✓			✓							✓
Velasquez et al. [6]			✓		✓	✓	✓						✓
Tabatabai et al. [7]	✓	✓						✓	✓	✓	✓	✓	✓
Gedafa et al. [8]		✓		✓				✓	✓				✓
Islam et al. [9]			✓			✓							✓
Ariawan et al. [10]	✓						✓						✓
Albayati and Alani [11]	✓												✓
Asefzadeh et al. [12]			✓			✓							✓
Lee et al. [13]	✓					✓	✓						✓
BELLS [14]		✓		✓				✓	✓				✓

## 5. Performance of Models

Performance Comparison of the developed models investigated in this study shows that most of the models have satisfying accuracy. Among the studied models, the model developed by Tabatabai et al. [7] has good accuracy, but accessibility to information such as asphalt mixture characteristics is challenging. BELLS [14] and Gedafa et al. [8] models do not require climatic information like solar radiation and input variables of these models are typically accessible. These models can be employed for prediction of depth temperature of asphalt layers with good accuracy and low prediction bias.

## 6. Local Calibration of Models

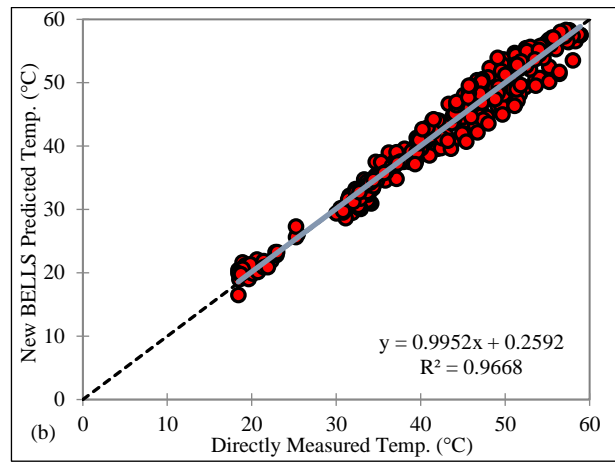
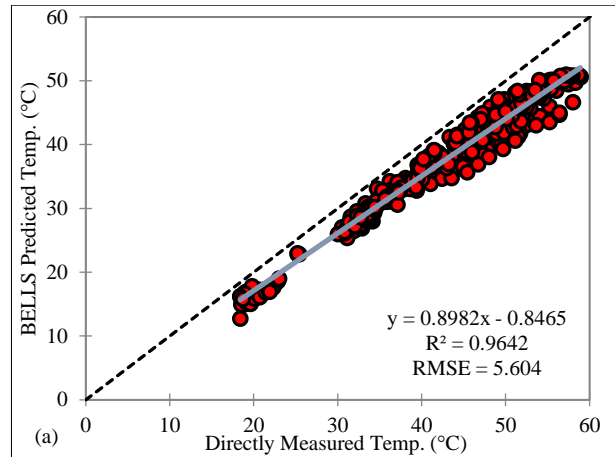
Evaluation of predictive models for the depth temperature of asphalt layers in different climatic conditions and local materials indicates that there is a need to calibrate the original models to develop new models for use in these local conditions. There are two general calibration approaches: an exponential fit of uncalibrated model outputs, and updating model coefficients using nonlinear multiple regression [16].

Asefzadeh et al. [12] calibrated the Park et al. [17] model to predict the depth temperature of asphalt layers at any time of the day. The modified model has satisfying accuracy and low bias. Furthermore, using this model, the accuracy of the back calculation of the characteristics of the asphalt layers obtained from the Falling Weight Deflectometer (FWD) test was enhanced. Solatifar et al. [15] showed that the BELLS model has a weak performance in predicting the depth temperature of asphalt layers in newly constructed pavements in hot climate areas. Therefore, they used a multi parametric linear fitting (regression) to develop a new model. As can be observed in "Figure 1", the developed model [15] predicts the depth temperature of asphalt layers with excellent precision and very low bias.

## 7. Conclusions

In this paper, a comprehensive analysis was carried out on twelve developed regression-based models for prediction of depth temperature of asphalt layers. The following conclusions can be drawn from this study:

- All models studied in this research, have acceptable results in predicting the depth temperature of asphalt layers, that were very close to the laboratory/field measured values.
- The availability of input variables is a prominent parameter in selecting the suitable prediction model. The greater number of input variables, the higher the prediction accuracy.



**Figure 1. Predicted vs. measured values of depth temperature: a) BELLS model, b) Solatifar et al. model [15]**

- Sensitivity analysis shows that the air temperature has the most impact on the depth temperature, especially during the hours of the day that the air temperature is high. Several researchers have also proposed the shadow effect as a significant parameter in the prediction of depth temperature of asphalt layers.
- Among the investigated models, according to the variety of parameters used in the model development, performance, considering the effect of various parameters, such as the shadow effect, latitude, etc., BELLS model introduced as one of the best regression-based models for prediction of depth temperature of asphalt layers. The model developed by Solatifar et al. [15] as a new version of the BELLS model showed very good accuracy ( $R^2 = 0.97$ ) and low bias for newly constructed pavements.
- Evaluation of depth temperature predictive models in different climatic conditions and local

materials shows the need for calibration of original models to develop new models for use in local conditions. Furthermore, other factors such as material characteristics, etc. can be employed to enhance the applicability of the models.

## 8. References

- [1] Minhoto, J. C., Pais, J. C. and Pereira, A. A. (2005). "Asphalt Pavement Temperature Prediction", *Transportation Research Record: Journal of the Transportation Research Board (TRR Journal)*, Vol. 1, No. 1919, pp. 96-110. doi: <https://doi.org/10.3141/1919-11>
- [2] Ramadhan, R. H. and Wahhab, A. H. (1997). "Temperature Variation of Flexible and Rigid Pavements in Eastern Saudi Arabia", *Journal of Building and Environment*, Vol. 32, No. 4, pp. 367-373, Printed in Great Britain. doi: [https://doi.org/10.1016/S0360-1323\(96\)00072-8](https://doi.org/10.1016/S0360-1323(96)00072-8)
- [3] Diefenderfer, B. K., Al-Qadi, I. L. and Reubush, S. D. (2002). "Prediction of Daily Temperature Profile in Flexible Pavements", 81<sup>st</sup> Annual Meeting 'Transportation Research Board', Washington, D.C., USA.
- [4] Diefenderfer, B. K., Al-Qadi, I. L. and Diefenderfer, S. D. (2006), "Model to Predict Pavement Temperature Profile: Development and Validation", *Journal of Transportation Engineering*, Vol. 132 Issue. 2. doi: [https://doi.org/10.1061/\(ASCE\)0733-947X\(2006\)132:2\(162\)](https://doi.org/10.1061/(ASCE)0733-947X(2006)132:2(162))
- [5] Hassan, H. F., Al-Nuaimi, A. S., Taha, R. and Jafar, T. M. A. (2005). "Development of Asphalt Pavement Temperature Models for Oman", *Journal of Engineering Research*, Vol. 2, No. 1. pp. 32-42.
- [6] Velasquez, R., Marasteanu, M., Clyne, T. R. and Worel, B. (2008). "Improved Model to Predict Flexible Pavement Temperature Profile", 3<sup>th</sup> International Conference on Accelerated Pavement Testing (APT). Impacts and Benefits from APT Programs, Madrid, Spain.
- [7] Tabatabaie, S. A., Ziari, H. and Khalili, M. (2008). "Modeling Temperature and Resilient Modulus of Asphalt Pavements for Tropic Zones of Iran", *Asian Journal of Scientific Research*, Vol. 1, pp. 579-588. doi: [10.3923/ajsr.2008.579.588](https://doi.org/10.3923/ajsr.2008.579.588)
- [8] Gedafa, D. S., Hossain, M. and Romanoschi, S. A. (2014). "Perpetual Pavement Temperature Prediction Model", *Journal of Road Materials and Pavement Design*, Vol. 15, No. 1, pp. 55–65, doi: <http://dx.doi.org/10.1080/14680629.2013.852610>
- [9] Islam, M. R., Ahsan, S. and Tarefder, R. A. (2015). "Modeling Temperature Profile of Hot-Mix Asphalt in Flexible Pavement", *Journal of Pavement Research and Technology (IJPRT)*, Vol. 8, Issue. 8, No. 1, pp. 47-52.
- [10] Ariawan, A., Sugeng Subagio, B. and Hario Setiadji, B. (2015). "Development of Asphalt Pavement Temperature Model for Tropical Climate Conditions in West Bali Region", 5<sup>th</sup> International Conference of Euro Asia Civil Engineering Forum (EACEF-5), *Procedia Engineering*, Vol. 125, pp. 474-480. Doi: <https://doi.org/10.1016/j.proeng.2015.11.126>
- [11] Albayati, A. H. K. and Alani, A. M. M. (2015). "Temperature Prediction Model for Asphalt Concrete Pavement", 14<sup>th</sup> Annual International Conference on Pavement Engineering and Infrastructure, Liverpool, UK.
- [12] Asefzadeh, A., Hashemian, L. and Bayat, A. (2017) "Development of Statistical Temperature Prediction Models for a Test Road in Edmonton, Alberta, Canada", *International Journal of Pavement Research and Technology*, Vol. 10, Issue. 5, pp. 369-382. doi: <https://doi.org/10.1016/j.ijprt.2017.05.004>
- [13] Li, Y., Liu, L. and Sun, L. (2018). "Temperature Predictions for Asphalt Pavement with Thick Asphalt Layer", *Construction and Building Materials*, Vol. 160, pp. 802-809. doi: <https://doi.org/10.1016/j.conbuildmat.2017.12.145>
- [14] Stubstad, R. N., Baltzer, S., Lukanen, E. O. and Ertman-Larsen, H. J. (1994). "Prediction of AC Mat Temperatures for Routine Load-Deflection Measurements, in 4<sup>th</sup> International Conference on the 'Bearing Capacity of Roads and Airfields', Minneapolis, Minnesota, USA.
- [15] Solatifar, N., Abbasghorbani, M., Kavussi, A. and Sivilevičius, H. (2018). "Prediction of Depth Temperature of Asphalt Layers in Hot Climate Areas", *Journal of Civil Engineering and Management*, Vol. 24, No. 7, pp. 516-525. doi: <https://doi.org/10.3846/jcem.2018.6162>
- [16] Solatifar, N. (2018). "Analysis of Conventional Dynamic Modulus Predictive Models of Asphalt Mixtures", *Amirkabir Journal of Civil Engineering*. (in Persian)
- [17] Park, D. Y., Buch, N. and Chatti, K. (2001). "Effective Layer Temperature Prediction Model and Temperature Correction Via Falling Weight Deflectometer Deflections", *Transport. Res. Rec. J. Transport. Res. Board*, No. 1764, pp. 97–111.