Selection of regression model for prediction of maximal daily pavement temperatures at Awbari in Libya

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Abstract

This paper presents a part of the research undertaken to develop models to predict high and low asphalt pavement temperatures in the Libya. A pavement monitoring station was set-up at several locations in Libya, to monitor air and pavement temperatures at different depths, wind speed and solar radiation. Daily minimum and maximum temperatures were recorded. Regression analysis was used to develop models for maximal daily pavement surface temperature, using maximal daily air temperature, day of the year, wind speed and solar radiation as predictors. Several criteria are used for selection of the best model. Results were compared with existing SHRP and LTPP models.

Keywords: Pavement temperature, model selection, Cross-validation, Mallow's Cp, R^2 adjusted.

1. Introduction

A significant factor that affects the performance and life span of a pavement is the influence of temperature. Temperature can contribute to certain common types of asphalt pavement distresses such as permanent deformation or rutting (typically associated with high temperature environments), bleeding, and thermal cracking (associated with low temperature environments). The Strategic Highway Research Program (SHRP) established the Long Term Pavement Monitoring Program (LTPP) program in 1987 to support a broad range of pavement performance analyses leading to improved engineering tools to design, construct, and manage pavements Diefenderfer, *et al.* (2002). Libya in general, has a different environment from that of the North America and Gulf area. The applicability of the recent SHRP and LTPP developments in the US to Libya's environmental conditions needed to be evaluated. Monitoring stations were set-up at eight locations in Libya to collect data on air temperature, wind speed, solar radiation and pavement temperatures at various depths.

Here we presents a part of this research, namely the model selection for prediction of maximal daily temperatures of the surface of the pavement, using maximal daily air temperature, day of the year, wind speed and solar radiation, based on data from Awbari, one of the eight locations where date were collected. Awbari is situated in desert part of Libya, latitude 24°13'N and longitude 23°18'E.
The temperature data used in analysis were collected in the period from 1st of January 2012 to 31st of December 2012, at Awbari location. The temperatures of the air and pavement were registered each 15

seconds, as well as the wind speed and solar radiation. Maximal daily temperatures of the air and pavement were extracted for each day of observed period. Based on these data, using regression analysis**,** models for maximum daily pavement surface temperatures were obtained. Similar research was done in Awadat Salem *et al.* (2014) for Al Kufrah region in Libya, and in Matić *et al.* (2011) for pavement temperatures in Serbia. Here we discuss the selection of the best regression model, applying six criteria.

Data were analyzed using the statistical package Statistica 12 (StatSoft Inc., Tulsa, OK, USA), university license for Novi Sad University, and the R programming language (R 3.1.2).

2. Data analysis

Prior to discussing the temperature models, a brief summary of the air and pavement temperature data is presented. In table 1 the descriptive statistics for maximal daily temperatures for Awbari are given, including the mean, 95% confidence interval (CI), minimum, maximum, standard deviation (St.Dev) and standard error (St.Err).

Table 1: Awbari maximal daily air and pavement surface temperatures

Max temp	Mean	-95%CI	95%CI	Median	Min	Max	St.Dev	Skew.	Kurt.
Air	40.83	40.14	41.52	42.05	21.96	52.58	6.70	-0,39	-0,95
Surface	55.41	54.34	56.48	57.72	32.16	72.46	10.41	-0,39	-0,99

In figure 1 the scatter plot of maximal daily temperatures of the surface of the pavement against maximal daily air temperatures showing linear relationship. Thus, the first variable in the model is maximal daily air temperature. Figure 2 presents maximal daily pavement surface temperature and air temperatures during study period (1.1.2012. - 31.12.212), showing non linear dependance on the day of the year.). To establish the periodicity in behaviour of the maximal daily pavement surface temperatures we calculated periodogram (Box et al., 2008) and singled out the harmonic component that has the highest contribution to the mean of the total sum of squares of time series. Therefore, time - day of the year, denoted by t, was included in the model as t^2, $\sin\left(\frac{2\pi t}{182}\right)$ and $\cos\left(\frac{2\pi t}{182}\right)$**.** Days of the year were coded with codes: 0 for 1.1.2012, up to 366 for 31.12.2102.

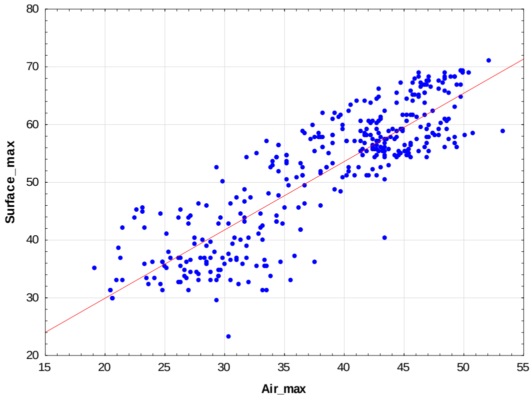

Figure 1 Maximal daily surface against maximal daily air temperatures

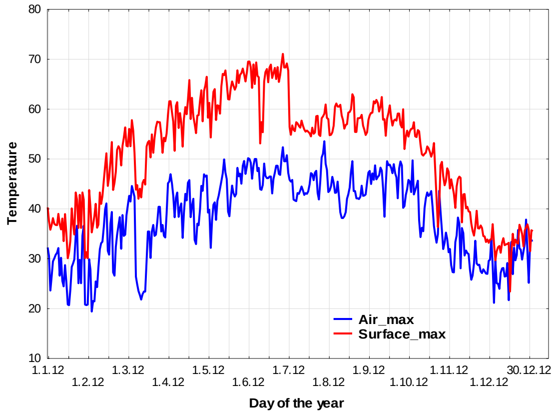

Figure 2 Maximal daily surface and air temperatures in the year 2012

Since daily maximal daily surface pavement temperature is affected by factors other than daily maximal air temperature and day of the year, other parameters were considered in order to improve the model, namely wind speed (m/s) and solar radiation (W/m^2). In table 2 all considered models are listed.

Table 2 List of all considered models

Model No.	Predictors
1	Air_max, t, t^2, SR, WS, sin $(\frac{2\pi t}{182})$, cos $(\frac{2\pi t}{182})$.
2	Air_max, t, t^2, SR, sin $(\frac{2\pi t}{182})$, cos $(\frac{2\pi t}{182})$.
3	Air_max, t, t^2, SR, WS, sin $(\frac{2\pi t}{182})$
4	Air_max, t, t^2, WS, sin $(\frac{2\pi t}{182})$, cos $(\frac{2\pi t}{182})$.
5	Air_max, t, t^2, WS, sin $(\frac{2\pi t}{182})$
6	Air_max, t, t^2, sin $(\frac{2\pi t}{182})$, cos $(\frac{2\pi t}{182})$.
7	Air_max, t, t^2, SR, sin $(\frac{2\pi t}{182})$
8	Air_max, t, t^2, WS, SR, cos $(\frac{2\pi t}{182})$
9	Air_max, t, t^2, SR,WS

Legend: Air_max – maximal daily air temperature, *t* – day of the year, SR – solar radiation, WS – wind speed,

In order to select the best model, six criteria were applied. Adjusted R^2, Mallow's Cp, Akaike's information criterion (AIC), Bayesian information criterion (BIC), as well as two algorithms for cross-validation: leave one out cross-validation and 15-fold cross-validation. The split of 364 observations into 15 groups was done randomly with 100 replications. All criteria except Adjusted R^2 are based on balancing model complexity against quality of model's fit. The results are given in table 3. The values in red denote the best model according to corresponding criteria.

Table 3 The best models, according to six criteria.

Model No.	Mallows' Cp	Adjusted R^2	AIC	BIC	CV1	CV15
1	**8,0000**	**0,9258**	**1849,993**	1885,067	**9,3963**	**9,4155**
2	10,3375	0,9251	1852,401	**1883,578**	9,4549	9,4699
3	11,0489	0,9250	1853,119	1884,296	9,4604	9,4783
4	13,8200	0,9244	1855,902	1887,079	9,5452	9,5642
5	16,2866	0,9237	1858,343	1885,623	9,5916	9,6090
6	16,6907	0,9236	1858,743	1886,023	9,6147	9,6293
7	28,4299	0,9212	1870,152	1897,432	9,9076	9,9210
8	28,7881	0,9213	1870,578	1901,755	9,9420	9,9597
9	29,0213	0,9211	1870,717	1897,997	9,9324	9,9471

Legend: CV1 – leave on out cross-validation, CV15 - 15-fold cross-validation

For repeated 15-fold cross-validation the empirical distributions of CV-test criterion for applied methods may be obtained and compared (Figure 3).

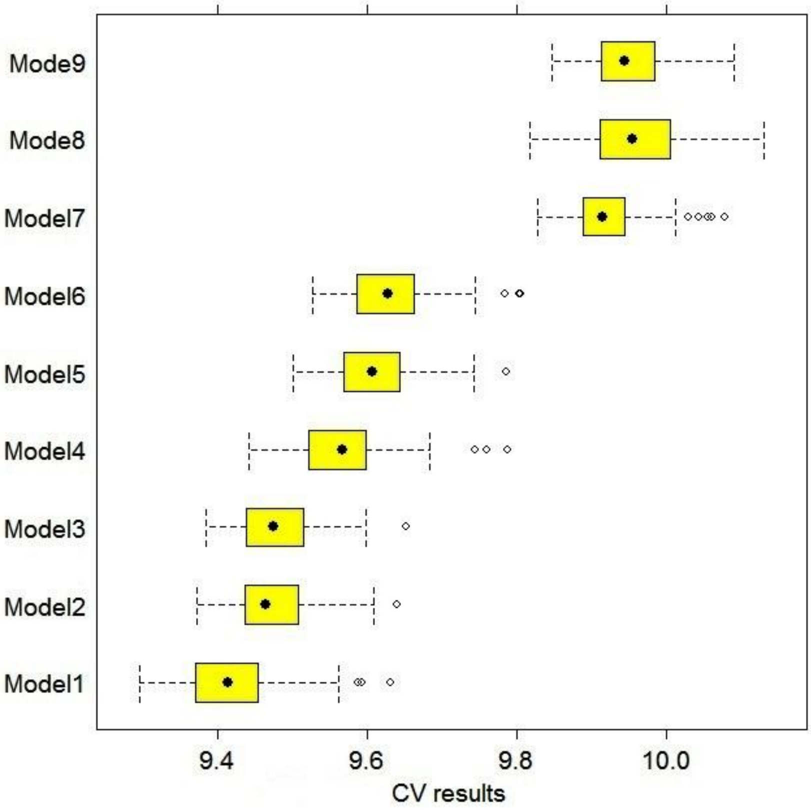

Figure 3: Distribution of repeated 15-fold CV with 100 replications

The best model, according to all criteria, except BIC, is the model including all predictors. Coefficients for this model are given in table 4.

Table 4 Coefficients of the best model to predict maximal daily surface pavement temperature

N=364	Regression Summary for Dependent Variable: Surface_max R= 0,96294771 R^2=0,92726829 Adjusted R^2= 0,92583817 F(7,356)=648,39 p<0,0000 Std.Error of estimate: 3,0303			
	b	Std.Err. of b	t(356)	p-value
Intercept	17,88695	1,242418	14,3969	0,000000
Air_max	0,61500	0,035644	17,2541	0,000000
t	0,20130	0,012533	16,0618	0,000000
t^2	-0,00061	0,000033	-18,3284	0,000000
WS	-0,13927	0,066870	-2,0827	0,037995
SR	0,00242	0,000864	2,7964	0,005448
$\sin(2\pi t/182)$	-1,26987	0,266014	-4,7737	0,000003
$\cos(2\pi t/182)$	-0,66550	0,296175	-2,2470	0,025254

3. Comparison of the best model with SHRP and LTPP models

In order to compare the best model and SHRP and LTPP high temperature prediction models for pavement surface temperature, we consider the SHRP model

$$T_{surf}^{max} = (T_{air}^{max} - 0{,}00618 * Lat^2 + 0.2289 * Lat + 42{,}4) * 0{,}9545 - 17{,}78$$

and LTPP model

$$T_{surf}^{max} = 54{,}32 + 0{,}78 * T_{air}^{max} - 0{,}0025 * Lat^2 - 15{,}14 log_{10}(25)$$

(Hassan et. al 2005), where T_{surf}^{max} is the maximal daily pavement surface temperature, and T_{air}^{max} is the maximal daily air temperature in °C, and *Lat* is latitude in degrees. Latitude for Awbari is equal to 26°46'N (26.7667).

In figure 4 observed values and predicted values in the best model are presented together with values obtained in SHRP and LTPP high temperature prediction models. It can be seen that the predicted maximal daily surface pavement temperatures by SHRP and LTPP models are higher than both the observed values and the maximal surface pavement temperature predicted by the best model. Therefore, the developed model is more representative of Awbari climatic conditions. SHRP and LTPP models would be expected to result in a more conservative selection of the Performance Grade (PG) binder.

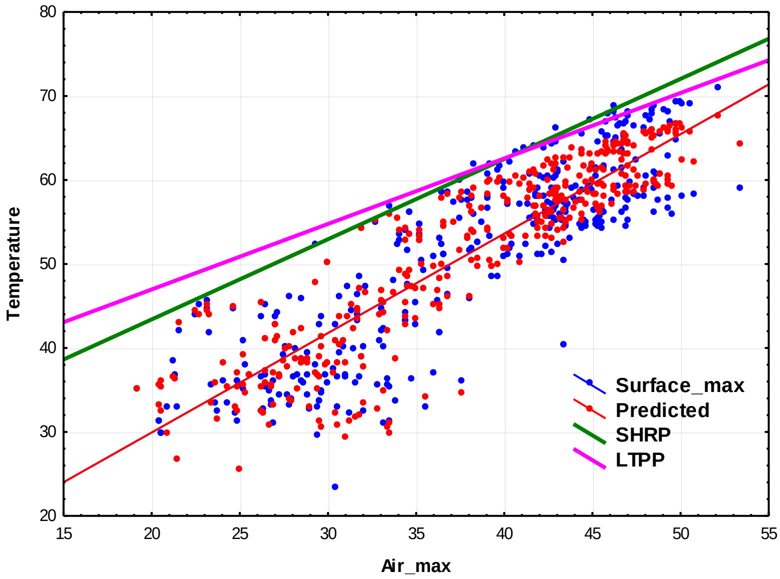

Figure 4: Comparison between daily maximum surface pavement temperature prediction model and SHRP and LTPP models.

4. Conclusions

Regression models for predicting maximal daily pavement surface as a function of maximal daily air temperature, day of the year, wind speed and solar radiation are considered. The best model was selected using adjusted R^2, Mallows' Cp, AIC, BIC and cross-validation. The comparison of the best model with SHRP and LTPP models indicates that the latter models would estimate higher pavement temperatures for Awbari, Libya. Therefore, these models would be conservative in the selection of Performance Grade (PG) binders.

5. Acknowledgments

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