Temperature Based GIS Approach
For Asphalt Binder Specifications in Lebanon

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ABSTRACT

The Strategic Highway Research Program has developed a new system for specifying asphalt materials referred to as *Superpave*. *Superpave* mix design procedure has proved its superiority over other methods, and is now adopted in some countries including the United States. Within the system, asphalt binders are characterized according to the upper and lower pavement service temperatures.

Transition to this performance grading system in Lebanon requires dividing the country into *temperature zones* defined by the maximum and minimum air temperatures over a typical year. These are then converted into pavement temperatures using suitable algorithms. Based on data from fourteen weather stations, temperature contour maps were developed and those served to achieve the required bitumen performance grades.

In this paper, the GIS methodology adopted is illustrated. It forms an integrated approach which is also flexible and user-friendly. It can be developed further to incorporate traffic data such as vehicle speed and traffic volume.

INTRODUCTION

Asphalt is one of the oldest building materials. It is used mainly in pavement construction and maintenance. The selection of the type and grade of asphalt depends on the type of construction and the climate of the project area. The consistency of asphalt is greatly affected by temperature. Asphalt gets hard and brittle at low temperatures and becomes soft at high temperatures. Consequently, the grade of the asphalt cement should be selected according to the geographic area.

The asphalt cement specifications were typically based on measurements of viscosity, penetration, ductility and softening point temperature. These measurements are not sufficient to properly describe the viscoelastic and failure properties of asphalt cement that are needed to relate asphalt binder to mixture properties and to pavement performance. Since properties of the asphalt are highly sensitive to temperature, all tests must be conducted within very tight tolerances.

In addition to the above, asphalt cement is further dependent on the loading rate. As shown in Figure 1 the amount of asphalt flows could be the same for one hour at 60 ^{o}C or 10 hours at 25 ^{o}C. In other words, the effect of time and temperature are related; the behavior at high temperature over short time periods is equivalent to what occurs at lower temperature and long durations. This is often referred to as the time-temperature shift or superposition concept of asphalt cement.

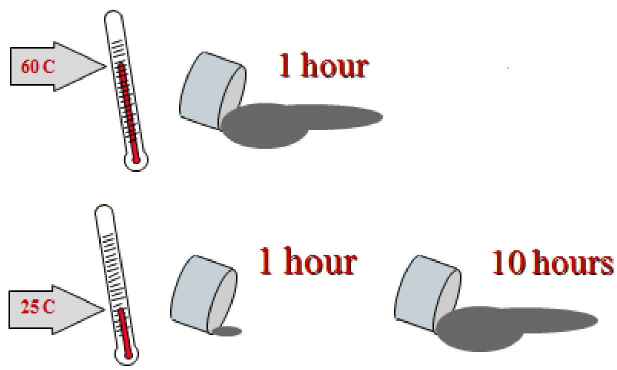

Figure 1: Effect of Time and Temperature on Asphalt Behaviour.

In hot conditions (e.g. desert climate) or under sustained loads (e.g., slow moving or parked trucks), asphalt cement acts like a viscous liquid. In cold climates (e.g., winter days), however, or under rapidly-applied loads (e.g., fast moving trucks) asphalt cement behaves like an elastic solid. When excessively loaded, it may become too brittle and crack.

The new Superpave system incorporates performance based asphalt material characterization with the design environmental conditions to improve performance by controlling rutting, low temperature cracking and fatigue cracking. Unlike previous specifications that require performing the test at a fixed temperature and varying the requirements for different grades of asphalt, the Superpave specifications require performing the test at critical pavement temperature and fixing the criteria for all asphalt grades. The distinction among the various binder grades is the specified minimum and maximum temperatures at which the requirements must be met.

Laboratory tests that evaluate rutting potential use the maximum pavement design temperature, whereas tests that evaluate fatigue potential use the intermediate pavement design temperature. Thermal-cracking tests use the minimum pavement design temperature plus 10 ^{o}C. The minimum pavement design temperature is increased by 10 ^{o}C to reduce the testing time.

Although binder grades are classified according to high and low temperature categories, the binder is needed to be selected for a particular location. The Superpave software contains three methods by which the user can select an asphalt binder grade:

- Geographic Area
- Pavement Temperature
- Air Temperature

The aim of this paper is to show how Superpave specifications can be adopted to suit local conditions in Lebanon. Collected data from the operating weather stations is included in the analysis. Air temperatures are converted into pavement temperatures which are then used to develop a GIS temperature zoning map, which allows users to select binder grades for the climate at the project location.

TEMPERATURE ZONING OF LEBANON: DATA ACQUISITION AND GEOGRAPHICAL ATTRIBUTION

Meteorological Authority in Rafic El-Hariri International Airport- Beirut was approached to provide the research team with the available environmental data that has been collected up to the present time. Unfortunately, during the civil war most of the weather stations had stopped. Forty new weather stations were installed since the year 2000; some of them are not fully operational. Eventually, weather information from fourteen reporting stations was included in the analysis. For each year, the average maximum air temperature for hottest seven-day period was calculated and then the means and standard deviations for all the years of operation were computed. Similarly, the one-day minimum air temperature of each year was identified and the means and standard deviations of all the years of record were calculated. Table 1 presents a list of these stations with calculated average temperatures.

Table 1. Average minimum and seven-day maximum air temperature at different weather stations.

Station	7-day Maximum Temperature (ºC)			Minimum temperature (ºC)		
	Mean*	Std.*	98% Rel.**	Mean*	Std.*	98% Rel.
Beirut	32.5	1.2	34.3	5.9	1.5	3.0
Tripoli	30.0	1.0	33.3	1.9	1.7	-0.0
Zahle	38.5	1.6	40.6	-2.6	2.6	-7.5
Al Qaa	39.3	0.4	40.1	-2.7	1.1	-4.3
Kfar Chakhna	34.6	2.2	38.1	2.1	1.9	-1.5
Deir El- Ahmar	39.2	1.1	40.5	-7.4	2.2	-11.0
Les Cedres	28.6	2.7	33.0	-12.1	1.8	-15.1
Sour	35.3	2.4	38.7	3.6	2.1	-1.4
Quaraoun	36.1	1.9	39.2	-1.2	1.3	-3.7
Sir El-Dinnyeh	33.4	1.4	35.2	-1.2	1.4	-4.4
Baysour	32.9	2.8	37.6	0.6	2.7	-4.0
Dahr El-Baidar	29.2	2	32.5	-5.9	1.4	-9.0
Quartaba	30.5	1.6	33.8	-1.6	2.2	-6.2
Qoubayat	33.9	1.3	36.5	2.3	1.7	-1.2

*Mean: mean air temperature   Std.: standard deviation of temperature
** 98% Rel.: calculated air temperature at 98% reliability.

However, to select the asphalt binder grade the pavement temperatures are required, not the air temperatures. Therefore, the Superpave pavement temperature predictions algorithms [1] were used to convert the obtained air temperatures into pavement temperatures at 98% reliability level. The maximum pavement design temperature is calculated at a depth 20 mm below the pavement surface, and the minimum design temperature at the pavement surface taking the geographical locality into consideration as follows:

Maximum surface temperature

$$T_{s(max)} = T_{air(max)} - 0.00618 \cdot latitude^2 + 0.2289 \cdot latitude + 24.4$$

Maximum temperature at depth

$$T_{d(max)} = \left(T_{s(max)} + 17.8\right)\left(1 - 2.48\times10^{-3} d + 1.085\times10^{-5} d^2 - 2.441\times10^{-8} d^3\right) - 17.8$$

Where:

$T_{d(max)}$ = high pavement design temperature at a depth of 20 mm
T_{air} = seven-day average high air temperature, ^oC
Latitude= the geographical latitude of the project in degrees

Minimum surface temperature

$$T_{s(min)} = 0.859 T_{air(min)} + 1.7$$

Where:

$T_{air(min)}$ = 1-day minimum air temperature ^oC

Results are summarized in Table 2.

Table 2: Calculated Pavement Temperature

Station	**$T_{(air)max}$ C^o**	**Latitude**	**$T_{s(max)}$ @ Surface C^o**	**$T_{d(max)}$@ 20mm depth C^o**	**$T_{air(min)}$ C^o**	**$T_{s(min)}$@ Surface C^o**
Tripoli	33.85	34.45	66.10	61.92	-0.03	1.67
Beirut	34.34	33.82	66.45	62.26	3.02	4.29
Al-Qaa	40.06	34.35	72.29	67.81	-4.28	-1.98
Kfar-Chakhna	38.11	34.35	70.34	65.95	-1.48	0.43
Deir ElAhmar	40.52	34.12	72.69	68.19	-11.03	-7.77
Le Cedars	33.04	34.25	65.24	61.11	-15.12	-11.29
Sour	38.67	33.27	70.65	66.25	-1.36	0.53
Quaraoun	39.23	33.55	71.27	66.84	-3.72	-1.49
Sir Dinnyeh	35.19	34.38	67.42	63.18	-4.36	-2.05
Baysour	37.59	33.75	69.68	65.33	-4.03	-1.76
Zahle	40.61	33.83	72.72	68.22	-7.48	-4.73
Dahr Baidar	32.51	33.82	64.61	60.51	-9.04	-6.06
Quartaba	33.76	34.1	65.93	61.76	-6.23	-3.65
Qoubayat	36.50	34.57	68.78	64.47	-1.20	0.67

A recent study by Denneman [2] compared the Superpave model and Viljoen model [3] for temperature predictions against new measured set of pavement temperature taken in South Africa. He found that the Superpave results overestimate the surface temperature at low air temperatures and underestimate of the surface temperature at high air temperatures.

Contour maps for both the minimum temperature and the average maximum consecutive seven-day pavement (at 20 mm depth) temperature were developed. These two maps are needed to be superimposed to define zones according to the minimum and maximum pavement temperatures. For practical purposes, the administrative boarder of each area is also considered.

GIS METHODOLOGY

The locations of weather stations were provided in data sheets along with the average maximum and minimum calculated pavement temperatures (Table 2). These data sheets were imported into GIS to be displayed and projected over the map of Lebanon.

Since temperature is directly related to elevation, the contour lines of Lebanon were converted into Digital Elevation Model (DEM) in order to create an elevation surface. The weather stations were then overlaid on top of the DEM of Lebanon in order to see their geographical spread. These are given in Figure 2.

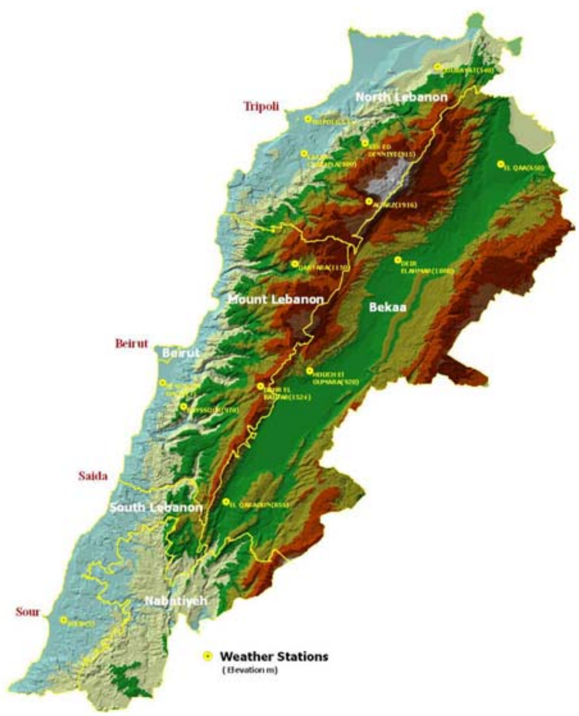

Figure 2: Distribution of Weather Stations

Measurements of average maximum and minimum temperature values extracted from the weather stations need to be interpolated in order to estimate values as continuous surface. A Spline Interpolation technique was used; which estimated values using a mathematical function that minimizes overall surface curvature, resulting in a smooth continuous surface that passes exactly through the input weather stations points. Spline methods are described as deterministic because they are directly based on the surrounding measured values.

The Spline surface was produced to both maximum and minimum temperature as shown in Figure 3 below.

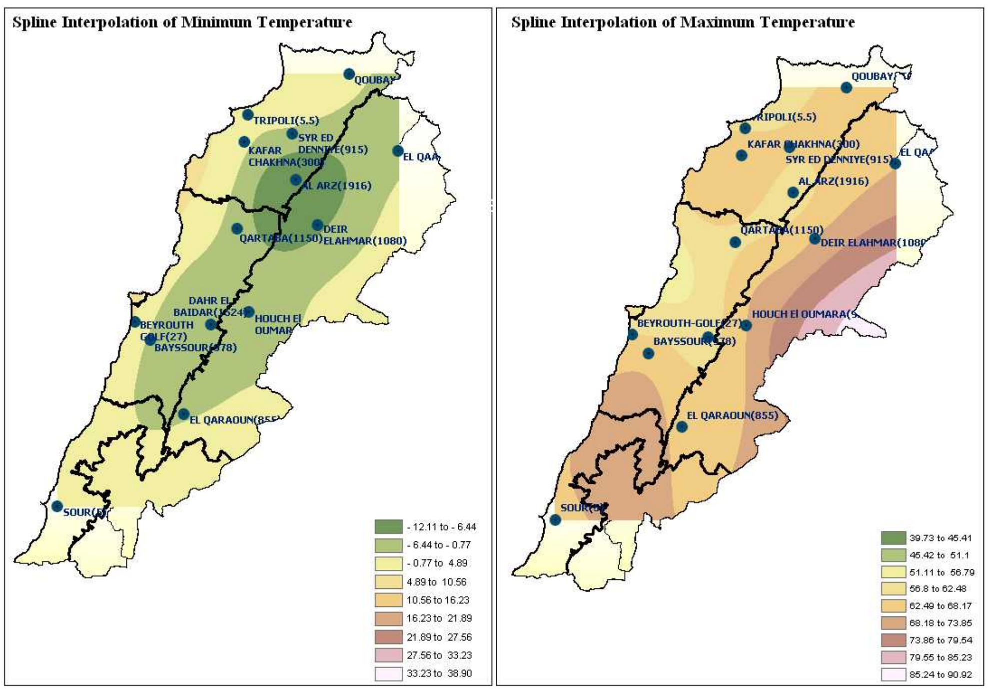

Figure 3: Spline Interpolation for Maximum and Minimum Temperatures

These surfaces show various temperature variations in different locations. The purpose here is to create one map were the temperature zones show obvious variations in both the highest and the lowest levels. These surfaces were also converted to temperature contour lines using Spatial Analyst.

Figure 4 below shows the iso-temperature lines for both the maximum and minimum pavement temperatures.

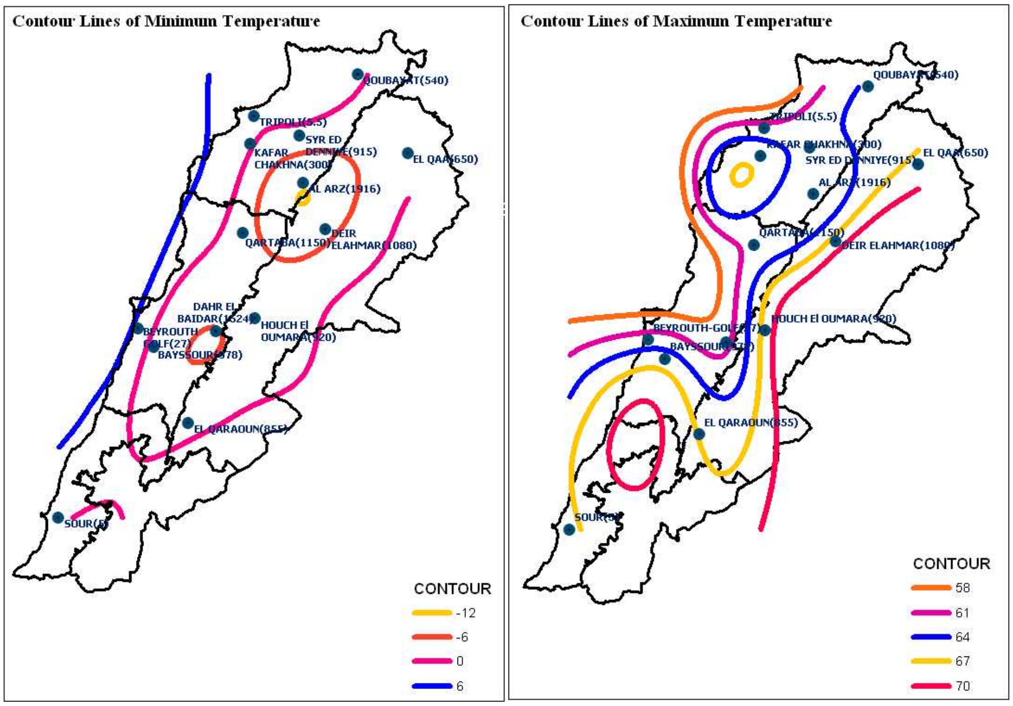

Figure 4: ISO-Contour Lines for Minimum and Maximum Pavement Temperatures

Both contour maps were then merged together in order to create one layer containing contour lines for both variations. The result was then related to the administrative regions in order to allow appropriate and practical analysis.

RESULTS AND DISCUSSION

The overlay process (shown in Figure 5) permitted the identification of many regions on the basis of minimum and maximum pavement temperatures.

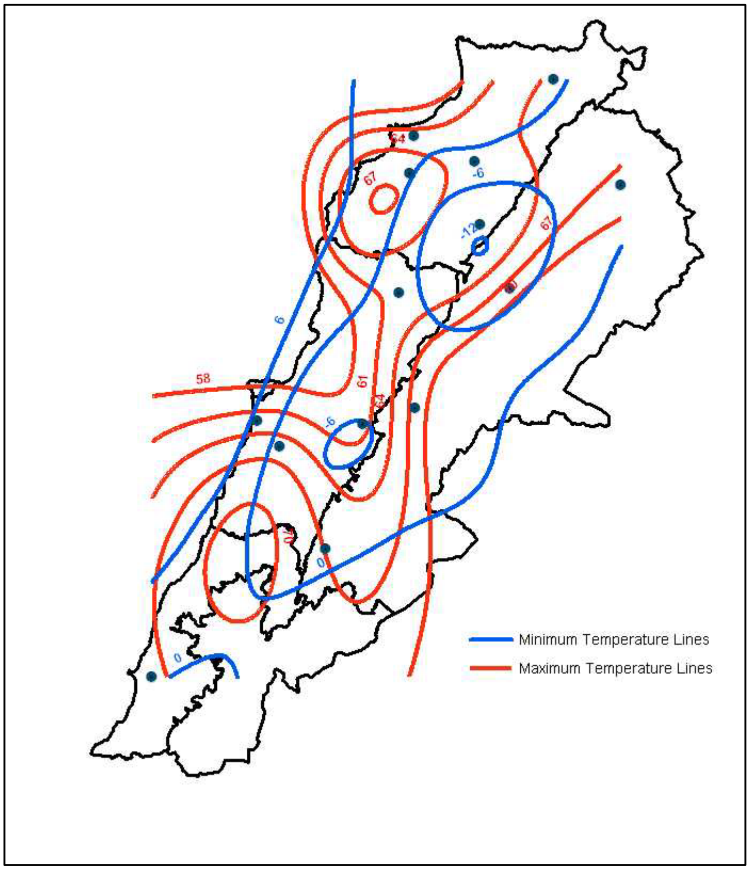

Figure 5: Maximum-Minimum Pavement Temperature Map of Lebanon.

It can be inferred from Figure 5 that the country is divided into three main regions: coastal, mountain area and inland area. Considering the Lebanese administrative regions, a practical number of work zones could be defined. Based on previous work [4] and recent research by one of the authors of this paper [5], three bitumen performance grades (PG) were recommended: PG 70-10, PG 70-4 and PG 64-16, where the first number denotes the 7-day maximum pavement design temperature and the second number refers to the minimum pavement design temperature. Figure 6 illustrates the proposed zones. The Superpave specifications for the selected grades can be found in Reference [6].

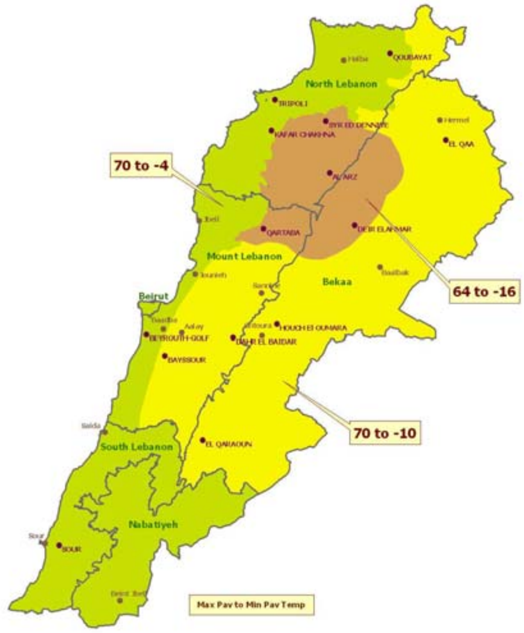

Figure 6: Proposed Pavement Design Temperatures for Lebanon

It must be emphasized that the proposed grades are for typical highway traffic conditions. For slow transient and standing loads or/and extraordinary high numbers of heavy traffic loads: an additional shift in the selected high temperature binder grade is proposed.

Future work will look into merging the map of roads with Figure 6, so the designer can directly select the required bitumen grade for his project based on the proposed map.

CONCLUDING REMARKS

- GIS has enabled the development of an intelligent map, which is a major component of the new pavement design procedure in Lebanon.
- Sufficient temperature base data has to be collected over long periods of time and with adequate spatial resolution.
- Information on traffic volumes and traffic speed is required to select the proper grade for a given highway. Future work will look into collecting such data to improve road grade prediction.

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