THE SELECTION OF URBAN PAVEMENT TYPE ACCORDING TO THE CARDINAL APPROACH

Kemal Selçuk ÖĞÜT¹ & Sabit KUTLUHAN²

SUMMARY

In this paper, the selection of the pavement type, such as the asphalt concrete, the cement concrete, the bituminous surface treatment, the sand asphalt, the cobble paving, the block paving, and the porous asphalt, is done with the cardinal approach, which is a branch of the group decision making with explicit multi-attribute evaluation, according to road users. The applied cardinal approach is based on the agreed set of attributes. At the first step, the attributes are classified into four benefit attributes and two cost attributes. The benefit attributes are the comfort, the safety, the aesthetic, and the ease of the maintenance and rehabilitation while the cost attributes are the road noise, and the maintenance frequency. At the second step, the judgement aggregation, which is the simple average of the rating value under each criteria, is developed. The third step, is consist of the application of the Technique for Order Preference by Similarity to Ideal Solution, TOPSIS, method. Finally, the closeness values are calculated to determine the selection of the urban pavement type according to road users.

INTRODUCTION

Pavement properties are the crucial issues of the urban road construction. The comfort, the safety, the road noise the aesthetic, the maintenance frequency and the ease of the maintenance and rehabilitation change according to the top layer of the pavement. Naturally, these changes affect the road users directly.

The urban pavement alternatives are the asphalt concrete, the cement concrete, the bituminous surface treatment, the sand asphalt, the cobble paving, the block paving, and the porous asphalt. These urban pavement types have various advantages and disadvantages according to the properties mentioned above. Thus, the selection of urban pavement types is a multi-attribute problem.

The aim of this study is to determine the ideal type of urban pavement type from the viewpoint of the road users. As they are not interested with the construction and maintenance costs, the economical evaluation of the pavements is not mentioned at this paper.

PAVEMENT ALTERNATIVES and THEIR ATTRIBUTES

In this study, initially, seven different pavement types and their six attributes mentioned above will be explained briefly.

¹ PhD, İstanbul Technical University, Civil Engineering Faculty, Transportation Dep.34469 İstanbul, TURKEY., Phone : +90 212 285 36 63, Fax: +90 212 285 34 20, E-mail: ksgut@ins.itu.edu.tr
² MSc, İstanbul Technical University, Civil Engineering Faculty, Transportation Dep.34469 İstanbul, TURKEY.
Asphalt Concrete: Asphalt concrete is the mixture of mineral aggregate and asphalt cement. It should be designed by the use of an adequate proportion according to the mix design procedures. The optimum asphalt ratio ranges from 4 to 7 percent generally. Asphalt concrete provides flexibility to prevent the cracks, waterproof to protect underlying pavement structure from the effects of water and load distributing to reduce the stresses being formed in the underlying pavement structure. After adequate rolling and a cooling period, the pavement has a high stability so that it can be opened to traffic immediately.

Cement Concrete: Portland cement concrete is a combination of cement, aggregates and water. The chemical reaction between the cement and water forms the bonds in the concrete that determine the properties of the hardened material. Unlike asphalt pavements, the portland cement concrete slab carries load through bending action [1]. Due to rigidity and high modulus of elasticity, cement concrete pavement distributes the load over a wide area and thus it deflects very little.

Bituminous Surface Treatment: One or more applications of sprayed – on liquid asphalt followed by a layer of suitable aggregate to protect and preserve the surface, maintain the structural integrity, or restore the surface texture and skid resistance of the roadway. Generally, bituminous surface treatments are performed on low volume roadways [2].

Sand Asphalt: In regions such as coastal areas where acceptable – quality sand is the only available aggregate, sand mixes can be used for economical surface courses that meet minimum requirements. They can be used for; roads and streets, where light, fast moving traffic is anticipated, surface and binder courses in pavement design for low pressure tires and nontraffic areas. When high stability is required, the gradation is improved by selecting and blending locally available sand. Mineral filler is added to increase the density and stability of the mix[3]. The maximum sized aggregate particle should be no more than 9.5 mm (3/8in) [4].

Cobble Paving: Cobbles are by definition naturally occurring water worn stones of a size suitable for paving. A cobblestone pavement consists of such stones, between 125 and 250 mm deep and rather less in length, set individually in a sand bed about 150 mm thick. Stones are laid to a random bond, rammed into place and covered with a 10 mm layer of sand to work into the joints under the action of traffic. Such a pavement is little more than a historical curiosity today as it provides neither a comfortable nor a stable surface under the action of modern motor traffic. Sett paving is a development of cobble paving which by virtue of a number of improvements provides a more comfortable, stable surface. Setts are generally of granite or quartzite, dressed into blocks varying in size [5].

Block Paving: There are two basic types of block paving; concrete types are referred to as blocks, and clays as bricks. Block paving consists of a large number of paving blocks or bricks laid in a course of graded sand or of concrete. There are two laying methods. The most popular is termed flexible paving, indicated that the blocks or bricks are laid on a sand bed and the joints filled with a fine silica sand. Rigid paving refers to, usually, clay bricks laid on a concrete or mortar bed with mortar joints. Amongst the blocks and bricks there is an enormous variety of shapes, sizes, colours, and textures now available [6]. Block or brick paving is suitable for sites where the traffic speed is unlikely to exceed about 50 km/h [5].
Porous Pavement: This type of pavement comprises the same material generally used for asphalt pavement, except that the fines (sand) are eliminated from the mix. Consequently, voids are left in the pavement. These allow rainwater to seep through [7].

Comfort: Pavement roughness or smoothness is the most important indicator of the pavement comfort. Pavement roughness is generally defined as an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle and thus the user [8]. Pavement smoothness is related only to the vertical changes in the level of the road in the wheelpaths of the vehicle, measured as a summary of vertical deviations that occur over an interval between two points. International roughness or smoothness index, IRI, is recognized as a general purpose and is expressed in units of inches/mile and meters/kilometer [9].

Safety: The evaluation of pavements for safety usually consider only slipperiness, in terms of skid resistance which is called surface friction by some agencies. There are, however, several components of safety evaluation, including skid resistance, ruts as they related to accumulation of water and the dangers of hydroplaning or ice accumulation, light reflectivity of the pavement surface, lane demarcation and debris or foreign objects [1]. A non-skid surface is essential, and proper grade control is required to provide rapid removal of surface water to minimize the potential for hydroplaning. All pavement surfaces should exhibit a sufficiently coarse texture to provide skid resistance. Aggregate types known to have a history of polishing should be avoided [4]. Deviations in the transverse and longitudinal profile of the pavement surface can generate a hazard to traffic, especially if they result in water standing on the pavement surface. Roughness can also create driver fatigue and therefore contribute to a safety problem [1].

Road noise: The sources of road noise are the engine noise, the transmission and the cooling noise, and rolling noise. At certain speeds the noise produced by cars is dominated by the sound of the tyres rolling on the road surface. At lower speeds, below 40-50 km/h, the engine noise also becomes important. The noise produced by the tyres depends on the road surface and the type of tyre. The most important factor is the roughness of the road surface (texture) and the tread of the tyre. Everyone is familiar with the effects of driving on paving stones, cement block paving or cobblestones. Average noise levels over 65 dB(A) can lead to health problems [10]. Using a low-noise surface reduces traffic noise at the source. A reduction of 3 dB(A) from 76 to 73 has the same effect as either reducing the traffic by half or doubling the distance from the source of the noise [11].

Aesthetic: The pavement type should be so selected that it should be harmonious with the natural environment and the reflect the natural landscape and historical structures. Especially, in touristic or historical cities, intensive importance should be given to select appropriate pavement type. For instance, the cobble stones or block/brick paving may be used aesthetically.

Maintenance frequency: Pavements should be designed according to an adequate design procedure and be constructed by the use of appropriate construction techniques so that it will not require the maintenance and rehabilitation during a long period of time. The maintenance and rehabilitation of pavement should take a short time and the road should be opened to traffic as soon as possible. The shorter the time, the more satisfaction for users. On the other hand, when the pavement needs for maintenance in a short time, not only routine maintenance costs, but also user costs increase. From the user point of view, the pavement which have low maintenance frequency is preferred in urban areas.
Ease of maintenance and rehabilitation: After the construction of the pavement, if any problem related to underlaying courses or substructure appears or if a new facility will be constructed under the pavement, the maintenance of the pavement should be completed by the way that is easy and fast. Especially, in urban areas that have the peak traffic periods, ease of maintenance and rehabilitation provides a big benefit to road users because of the decrease in delays. Partial or local maintenance allows the traffic to flow and thus the accessibility of the road network do not affect from the maintenance.

THE RANKING OF THE PAVEMENT ALTERNATIVES

“Technique for Order Preference by Similarity to the Ideal Solution”, TOPSIS, developed by Hwang and Yoon [12] for solving multi-criteria decision making problems. Hwang explained that a multi-criteria decision analysis problem maybe viewed as a geometric system. The m alternatives that are evaluated by n attributes are similar to m points in an n-dimensional space. Therefore, the most preferable alternative should be the point in that space that is closest to the ideal solution and farthest from the worst solution. The concept behind this method is that the most preferred alternative should have the shortest distance from the “high-level solution” and the farthest distance from the “low-level solution” from the geometrical point of view (i.e. Euclidean). The advantage is that this method is simple and yields an indisputable preference.

In order to calculate the rank of the alternatives, the technique for order preference by similarity to ideal solution, TOPSIS, is used. According to TOPSIS, the chosen alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative-ideal. TOPSIS consist of 5 steps such as:

1. Calculation of the normalized ratings.
2. Calculation of the weighted normalized ratings.
3. Identification of the positive-ideal and negative-ideal solutions.
4. Calculation of the separation measures.
5. Determination of the similarities to positive-ideal solution and ranking the preference order.

Evaluation of the criteria

The qualitative evaluation criteria is obtained from the paper presented by Ağar and Sütaş [13]. This evaluation is made only according to the road users and does not reflect the investment and operation costs. The scale from 1-9 to evaluate the criteria is used as follows:

- 9 for “Very Good”
- 7 for “Good”
- 3 for “Bad”
- 1 for “Very Bad”

The numerical evaluation is given in Table 1, where $X_1$ represents the comfort, $X_2$ represents the safety, $X_3$ represents the road noise, $X_4$ represents the aesthetic, $X_5$ represents the maintenance frequency, and $X_6$ represents the ease of the maintenance and rehabilitation. In order to determine the similarities to positive-ideal solution $X_1$, $X_2$, $X_4$, and $X_6$ are classified as benefit attributes, and $X_3$ and $X_5$ as cost attributes.
Table 1: The evaluation of the criteria according to road users.

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>X₁</th>
<th>X₂</th>
<th>X₃</th>
<th>X₄</th>
<th>X₅</th>
<th>X₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete</td>
<td>9</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Cement concrete</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Bituminous surface treatment</td>
<td>7</td>
<td>9</td>
<td>7</td>
<td>3</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Sand asphalt</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Cobble paving</td>
<td>7</td>
<td>3</td>
<td>7</td>
<td>9</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Porous asphalt</td>
<td>7</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Block paving</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>

Calculation of the Normalized Ratings

In order to get the individual normalized decision matrix D, the following equation is used.

\[ d_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{7} x_{ij}^2}} \]

The normalized ratings are given in Table 2. The attributes are assumed with the same weight; in other word, the weightiness of all attributes are equal to 1.

Table 2: The normalized ratings

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>X₁</th>
<th>X₂</th>
<th>X₃</th>
<th>X₄</th>
<th>X₅</th>
<th>X₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete</td>
<td>0.430</td>
<td>0.369</td>
<td>0.079</td>
<td>0.191</td>
<td>0.496</td>
<td>0.374</td>
</tr>
<tr>
<td>Cement concrete</td>
<td>0.430</td>
<td>0.475</td>
<td>0.238</td>
<td>0.445</td>
<td>0.071</td>
<td>0.160</td>
</tr>
<tr>
<td>Bituminous surface treatment</td>
<td>0.334</td>
<td>0.475</td>
<td>0.555</td>
<td>0.191</td>
<td>0.496</td>
<td>0.480</td>
</tr>
<tr>
<td>Sand asphalt</td>
<td>0.430</td>
<td>0.158</td>
<td>0.079</td>
<td>0.191</td>
<td>0.496</td>
<td>0.374</td>
</tr>
<tr>
<td>Cobble paving</td>
<td>0.334</td>
<td>0.158</td>
<td>0.555</td>
<td>0.573</td>
<td>0.071</td>
<td>0.480</td>
</tr>
<tr>
<td>Porous asphalt</td>
<td>0.334</td>
<td>0.475</td>
<td>0.079</td>
<td>0.191</td>
<td>0.496</td>
<td>0.053</td>
</tr>
<tr>
<td>Block paving</td>
<td>0.334</td>
<td>0.369</td>
<td>0.555</td>
<td>0.573</td>
<td>0.071</td>
<td>0.480</td>
</tr>
</tbody>
</table>

Identification of the Positive-Ideal and Negative-Ideal Solutions

In TOPSIS, the “high-level solution”, \( A^+ \) is defined as an alternative that is made of all the larger attribute values attainable and it is expressed as:

\[ A^+ = \left\{ \max_j d_{ij} \mid j \in J_1, \min_j d_{ij} \mid j \in J_2 \right\}_{i=1,7} \]

The “low-level solution”, \( A^- \), is made of all the smaller attribute values attainable and it is expressed as:

\[ A^- = \left\{ \min_j d_{ij} \mid j \in J_1, \max_j d_{ij} \mid j \in J_2 \right\}_{i=1,7} \]
A\(^+\) and A\(^-\) vectors are given in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive-Ideal Solution: A(^*)</td>
<td>0.430</td>
<td>0.475</td>
<td>0.079</td>
<td>0.573</td>
<td>0.071</td>
<td>0.480</td>
</tr>
<tr>
<td>Negative-Ideal Solution: A(^-)</td>
<td>0.334</td>
<td>0.158</td>
<td>0.555</td>
<td>0.191</td>
<td>0.496</td>
<td>0.053</td>
</tr>
</tbody>
</table>

### Calculation of the Separation Measures

The distance evaluation can be calculated by n-dimensional Euclidean distance, which represent distance from the “high-level solution” and “low-level solution”. For the high-level solution, highest attribute from benefits and lowest from costs, and for the low-level solution, lowest attribute from benefits and highest from costs are chosen. Thus, the formulations are:

- **High-level solution**
  \[ S_i^+ = \sqrt{\sum_{j=1}^{6}(d_{ij}^+ - d_{ij}^-)^2} \]

- **Low-level solution**
  \[ S_i^- = \sqrt{\sum_{j=1}^{6}(d_{ij}^- - d_{ij}^+)^2} \]

### Calculation of the Similarities to Positive-Ideal Solution and Rank Preference Order

The relative closeness \( C_i \) to the ideal solution can be expressed as follows:

\[ C_i = \frac{S_i^+}{S_i^+ + S_i^-} \]

where the \( C_i \) value lies between 0 and 1. The closer the \( C_i \) value is to 1 implies a higher priority of the \( i \)th alternative.

The Euclidean distances to the best, the worst, the relative closeness, and the ranking of the pavement alternatives are presented in Table 4.

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>( S_i^* )</th>
<th>( S_i^- )</th>
<th>( C_i )</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete</td>
<td>0.591</td>
<td>0.619</td>
<td>0.511</td>
<td>4</td>
</tr>
<tr>
<td>Cement concrete</td>
<td>0.379</td>
<td>0.683</td>
<td>0.643</td>
<td>1</td>
</tr>
<tr>
<td>Bituminous surface treatment</td>
<td>0.750</td>
<td>0.532</td>
<td>0.415</td>
<td>7</td>
</tr>
<tr>
<td>Sand asphalt</td>
<td>0.662</td>
<td>0.581</td>
<td>0.468</td>
<td>5</td>
</tr>
<tr>
<td>Cobble paving</td>
<td>0.579</td>
<td>0.713</td>
<td>0.552</td>
<td>3</td>
</tr>
<tr>
<td>Porous asphalt</td>
<td>0.720</td>
<td>0.572</td>
<td>0.443</td>
<td>6</td>
</tr>
<tr>
<td>Block paving</td>
<td>0.497</td>
<td>0.744</td>
<td>0.600</td>
<td>2</td>
</tr>
</tbody>
</table>

The relative closeness values show that, the cement concrete pavement is the ideal and the bituminous surface treatment is the worst pavement type at the urban area for the road users.
CONCLUSIONS

In this paper, seven pavement types applied at the urban areas, such as the asphalt concrete, the cement concrete, the bituminous surface treatment, the sand asphalt, the cobble paving, the block paving, and the porous asphalt have been investigated and evaluated from the road users point of view by using the “Technique for Order Preference by Similarity to the Ideal Solution”, TOPSIS, which is based on the agreed set of attributes. The attributes used are the comfort, the safety, the aesthetic, the ease of the maintenance and rehabilitation, the road noise, and the maintenance frequency. However, the investment, maintenance, and operation costs parameters, which do not influence the road user decisions, are not involved.

TOPSIS assumes that each attribute takes either monotonically increasing or monotonically decreasing utility. That is, the larger the attribute outcome, the greater the preference for benefit attributes and less the preference for cost attributes.

By using the TOPSIS, the cement concrete pavement is selected as the ideal pavement type for at the urban areas. Meanwhile, the block paving is ranked at the second order. The evaluation of the road users determined the bituminous surface treatment as the worst urban pavement type.

The pavement types and their attributes considered may vary locally. The local governments or municipalities may have different preferences or priorities, such as, the existing similar pavement types, the availability of local materials or so on., In addition, the investment and maintenance costs of the pavement play an important role at the pavement type selection. To sum up, the ranking of the pavement type is not unique and universal.

REFERENCES