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Original Article

Implementation of an Advisory Expert System for Evaluating the Quality of Asphalt Concrete

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Abstract - The construction of asphalt concrete pavement requires string control on its quality in the field. The percentages of each ingredient of the asphalt concrete mixture, including (various sizes of aggregates, filler, and asphalt cement binder) must be within the limits of laboratory mix design so that the final mixture will provide the required mechanical properties. Such control may not be achieved in the field due to expected variation in the gradation of aggregates and in providing the proper binder requirement. A statistical tolerance is accepted for such variation according to the specification, which is usually followed by a significant amount of engineering judgement for the decision of whether to accept or decline such deviations, verify its influence on the quality of asphalt concrete, and suggest the exact remedy to be taken and the penalty to be decided. In the present investigation, an advisory expert system is developed and presented. The knowledge base of the system contains heuristic rules extracted from the literature survey. It was felt that such an advisory system could meet the practical demand of road construction and quality control and assist in the decision on the suitability of the executed pavement according to the design requirements. A systematic process was developed to assess the decision maker in rejecting, accepting, or accepting the executed pavement with a discount in the cost (penalty).

Keywords - Advisory expert system, Asphalt concrete, Deviation, Specification, Mix design.

1. Introduction

Quality control on the production of asphalt concrete mixture is required to obtain a sustainable pavement with the required service life. Mosa et al. [1] stated that fixing the complex problems of pavement construction is nearly impossible without expert assistance. Developing an expert system is a very effective way to help the engineers to overcome these problems. Development stages of the expert system include system building, knowledge representation, knowledge acquisition, and system validation. The initial knowledge is obtained from literature reviews and through interviews and questionnaires.

This knowledge is converted to computer software. Zain et al. [2] described a prototype expert system that provides the proportion of the trial mix and provides recommendations on mix adjustment. The system was invented with the aid of a hybrid knowledge representation technique. It was revealed that the system is capable of selecting proportions of aggregates, mixing water, and supplementary cementitious materials.

Salam et al. [3] developed an expert system for the mix design of brick aggregate concrete. It was reported that the system is capable of selecting the proportions of mixing water, cement, and aggregates. The main issue of the developed system was the knowledge acquisition process, which was taken from technical literature and experts' opinions. Sarsam [4] developed an expert system to control and evaluate the quality of asphalt concrete mix constituents. The knowledge base of the system contains heuristic rules obtained from a literature survey and a consultant's experience. It was concluded that such a system could meet the practical demand of road construction and provide an instant decision on the remedy.

Ismail et al. [5] stated that the application of the expert system concept to monitor the quality control of asphalt concrete will enable the engineer to produce better quality materials, which are economically feasible, and to evaluate the finished product more reliably. Mahmood et al. [6] revealed that the expert system could be considered a new approach, which may lead to a better understanding of the influence of the variability in construction materials among the specification requirements, which will exhibit the correlation of expected performance and actual behaviour.

Sarsam [7] developed computerized methods for asphalt concrete mix design using stepwise linear fit. The method cares for the equation of aggregate gradation smoothing and also its location in the specifications area so that it is neither near the lower nor the upper limits. It was revealed that the decision can be given to the computer to choose one of the six equations of aggregate gradation for economic purposes by optimization process which can help in the final suggestion of the mix design. Almasoudi and Albayati [8] assessed the effect of deviation in the aggregate gradients of asphalt mixtures from the Job Mix Formula on the general mixture performance on the basis of statistical analysis.

Ramu et al. [9] present a computerized method for mix design of asphalt concrete pavement; The Linear Programming by Optimization method was adopted. It was concluded that the method can help to find combinations of variables that minimize or maximize a target cell. The aggregate gradation area is calculated from a graph by using the trapezoidal rule. Gradation aims to reduce the void space, thus improving the performance of the mix.

2. Problem Statement

Asphalt concrete pavement is widely used for road construction in Iraq by private or government companies. The quality of the final Asphalt Concrete pavement is expected to be variable. It depends mainly on the operation of the Asphalt Concrete mixing plant, the maintenance of the weight gages of the plant, the experience in mix design, and uniformity of the quality raw materials supplied to the plant. Variation in the quality of the pavement is unavoidable. The specification of the State Commission for Roads and Bridges SCRB [10] states that dense gradation of aggregates should be implemented, which provides a sound pavement surface capable of resisting the expected distresses throughout the design life of the pavement.

Due to the lack of such experience and the nature of the product, some deviations in aggregate gradation and Asphalt content from the laboratory-designed job mix occur. This investigation aims to evaluate the influence of such deviation in the gradation and binder content, which exceed the permissible tolerance amount on the mechanical properties of asphalt concrete and provide the decision on the remedy of such issue, which is considered as a change in product. It is unacceptable and will need an expert.

A systematic process was developed to assess the decision maker in rejecting, accepting, or accepting the executed pavement with a proper discount in the cost (penalty) based on scientific and logic rather than the experience of the engineer in charge, which is currently followed.

3. Development of the expert system

The developed expert system is designed to minimize subjective judgment. It implements computer processing and exhibits a variety of outputs with priorities for remedial treatment of the deviation of the properties from the required specifications. Three major concepts are involved in the development of the expert system. It includes the routine laboratory test results of Asphalt Concrete quality, which is usually performed as a quality control process throughout the construction of the pavement or after compilation of the construction (asphalt binder content, mineral filler percentage, gradation of aggregate, and void content). The mechanical properties of asphalt concrete include (Marshall Stability and flow), and the developed expert system technique.

3.1. Knowledge Acquisition

In developing an expert system, knowledge acquisition includes searching for domain knowledge from the available literature and public knowledge sources, such as those of consultant engineers' reviews and then merging them with the heuristic knowledge obtained from experts. Allwood [11] followed a similar process, and Cohn et al. [12].

3.2. Knowledge Representation

The most common form used in the representation process of the expert system is the (if-then) rule; such a rule keeps the running of data in the system until finalization and decision-making. A sample of such a rule can be shown in the next paragraph. Preran [13] reported a similar procedure.

3.3. System Logic

The typical expert system describes what to do in particular circumstances. Five major physical and mechanical variables must be considered in the evaluation process of the quality of asphalt concrete and in assessing the influence of deviations in such properties on the quality of the asphalt concrete mixture.

- Marshall stability in (kN), which represents the strength and resistance of asphalt concrete mixture to the shear stresses. Failure to exceed the minimum requirement of Marshall stability will provide an unacceptable mixture which should be rejected.
- Marshall flow in (mm), which represents the deformation of asphalt concrete under the shear stresses. Failure to maintain the flow value within the specification requirements will provide an unacceptable mixture.
- Air void content (Vv %), which represents the volume of voids in asphalt concrete mixture. The air void content is vital for the sustainability of asphalt concrete mixture, especially in regions with hot climates, as reported by Polaczyk et al. [14].
- Asphalt cement binder content (As %), which represents the percentage of binder in the mixture based on the weight of aggregates. Proper binder content can provide the required durability of asphalt concrete throughout the service life, as revealed by Zeiada et al. [15].
- Gradation of aggregates and filler as a percentage of each sieve size. G (j), where J=1, 2, 3, … N, and N is the sieve size in (mm).

The deviation of any of the above variables from the job mix tolerance and from the specification upper and lower limits will lead to one of the following action processes as suggested by the experts [16]:

a. Accept the work with cost reduction or discount RD (K).
b. Add an extra layer of asphalt concrete pavement of a specified thickness, AL (K).
c. Removing the asphalt concrete pavement layer RM (K).

For example, if the system shows RD (5) =30, it means a discount in the cost of the contract by 30%, which is attributed to the deviation in gradation where (5) is devoted to the gradation. Also, if it shows RM (4) =1, it means removing the layer due to failure in Asphalt content as (4) is devoted to the binder content.

The variables AL (K) and RM (K) take values of either zero or one when zero means taking no action, and one means layer addition or layer removal. For the final decision, the system will execute the following:

1. Addition of all RD (K) values:
   RD=$\sum 5\ (K)$ = RD (1) + RD (2) +RD (3) +RD (4) +RD (5) (1)

2. Execute the (logic OR) operation using all the values of AL (K) and RM (K)
   AL=AL (1) U AL (2) U AL (3) U AL (4) U AL (5) (2)

   RM=RM (1) U RM (2) U RM (3) U RM (4) U RM (5) (3)

If the value of any AL (K) is equal to one, then the AL value will have the same value as one, and the same is true for the variable RM.

If RM=1, the system will ask to remove the layer. If RM=0 and AL=1, then the system will ask to add an extra layer of 2 cm thickness if the failed layer was either base or binder courses. On the other hand, if the failed layer was the wearing course, then the system will ask to add an extra layer of 3 cm thickness.

If RM=0, AL=0, the system will ask for a discount RD

If RD > 100%, then it is considered as 100%.

RD (K), AL (K), and RM (K) are calculated when going through the five test variables as follows:

a. Marshall stability test Sm; If Sm value is lower than the minimum specification requirement, the deviation in Sm is calculated using the mathematical expression:

   P= $Ss - Sm$*100 (4)

   Where:
   Sm = Marshall Stability of the mix
   Ss = Minimum Marshall Stability requirement in the specifications. If P ≤ 15, then RD (1) = P

   If 15< P ≤ 30, then AL (1) =1
   If P > 30, then RM (1) =1

b. Marshall Flow Fm: The value of Fm is compared with the maximum and minimum requirements of the specification (F1 & F2). If Fm <F1, the deviation p from F1 is calculated using the formula:

   P = $F1 - Fm$*100 (5)

   $F1$= Upper limit of flow value.

   If Fm > F2, the deviation p from F2 is calculated using the formula

   P= $Fm - F2$*100 (6)

   $F2$= Lower limit of flow value.

   If P ≤ 30, then RD (2) = P/2 If P > 30, then AL (2) =1

c. Voids content Vv: The system compares Vv with minimum and maximum void requirements in specification (V1, V2).

If Vv <V1, then the deviation (p) from V1 is calculated as below:

$$P = V1 - V*100 \quad (7)$$

$V1$= Lower limit voids content

If P ≤ 2, then RD (3) =P*8 If P > 2, then AL (3) = 1

If V > V2, then the deviation (p) from V2 is calculated as below:

$$P = V - V2*100 \quad (8)$$

$V2$= Upper limit of void content

If P ≤ 6, then RD (3) = P *3 If P > 6, then AL (3) = 1

d. Asphalt content (As): The system compares (As) with minimum and maximum Asphalt content requirements as per the job mix tolerance G1 (N+1), G2 (N+1)

If (As) < G1 (N+1), then $P = C1(N+1) - As*100$ (9)

$G1(N+1)$ = Minimum asphalt content requirement

If (As) > G2 (N+1), then $P = As2 - G2(N+1)*100$ (10)

$G2(N+1)$ = Maximum asphalt content requirement

If P≤ 1.2 then RD (4) = 15* P

P≤ 2.2, then AL (4) = 1
O > 2.2 then RM (4) = 1

e. Asphalt concrete mixture gradation G (J), [J= 1, 2, 3, …N]: The deviation is taken as an absolute value and not as a percentage. The value of G (J) is compared with the minimum and maximum values of % finer by weight G1 (J) and G2 (J) as per job mix tolerance. Also, the value of G (J) is compared with minimum and maximum % finer by weight requirements M (J). Z(J) of specification limits.

If M (J) ≤ G (J) < G1 (3), then PJ = G 1(J) – G (J)

If G (J) < M (J), then PJ = G1 (J) – M (J) + $M(J) - G(J)2$

If G2 (J) < G (J) ≤ Z (J), then PJ = G (J) – G2 (J)

If G (J) > Z (J), then PJ = Z (J) – G2 (J) + [G (J) – Z (J)] / 2

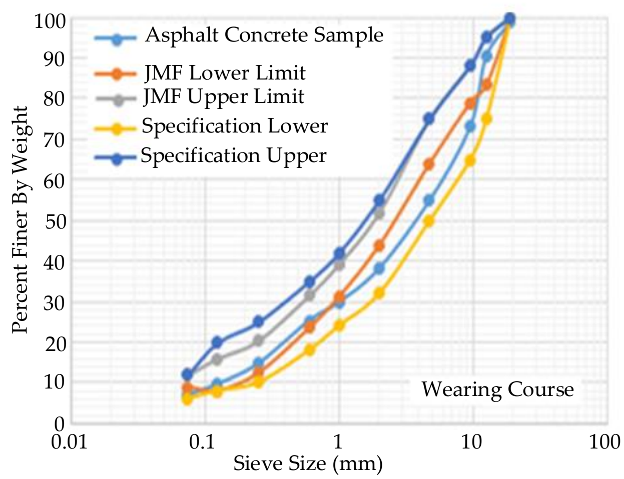
The value of RD (S) is calculated as below:

$$RD(5) = \sum n\, PJ \quad (11)$$

4. Results and Discussion

The developed expert system was examined for its validity on three asphalt concrete samples obtained from three different pavement layers. Figure 1 exhibits the test results of wearing the course mixture. It can be observed that there is a deviation in the gradation from the job mix formula at sieves of sizes (19, 9.5, 4.5, 2, 1, and 0.075) mm, including the mineral filler content. Moreover, the asphalt binder content was higher than the requirements, while the voids percentage was lower. Such variation in the gradation of aggregates from the job mix formula will impart the dense gradation required for sustaining the vehicular throughout the service life of the pavement.

On the other hand, higher binder content will cause bleeding and rutting of the pavement layer. The expert system logic has considered such issues. The expert system's decision was not to accept the work.

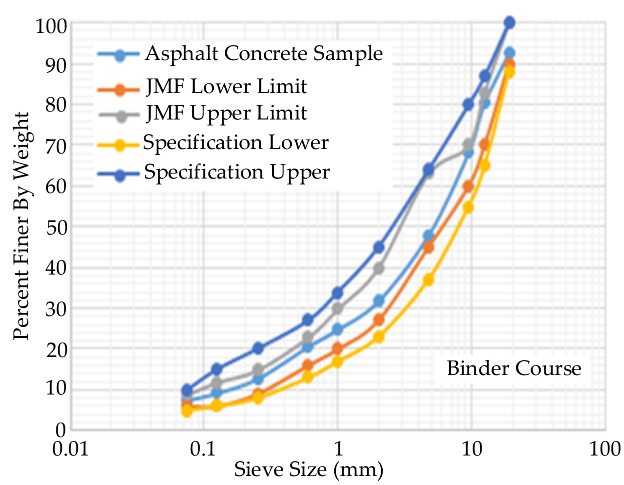


Asphalt Content 6.09%	**(5.4-5.9) %**
Marshall Stability 1763 Kg	**(815 kg Minimum)**
Marshall Flow 3.81 mm	**(2-4 mm)**
Voids 2.9%	**(3-5) %**
Fractured Faces 95 %	**(90 % Minimum)**
Specific Gravity 2.414	

Expert System Decision: Not accepted, Remove the layer due to deviations in gradation and voids and

Fig. 1 The output of the expert system for wearing the course pavement layer

Figure 2 demonstrates the test results of the binder course pavement layer. It can be noticed that the Marshall flow exceeds the limits, although it is within the tolerance of the job mix formula, while the voids filled with asphalt also exceed the specification limits. The lower voids content was a result of excess fine materials in the mixture. It was felt that such a mixture may exhibit rutting in the near future. The expert system decided to apply a cost reduction of 2 % for this pavement layer.

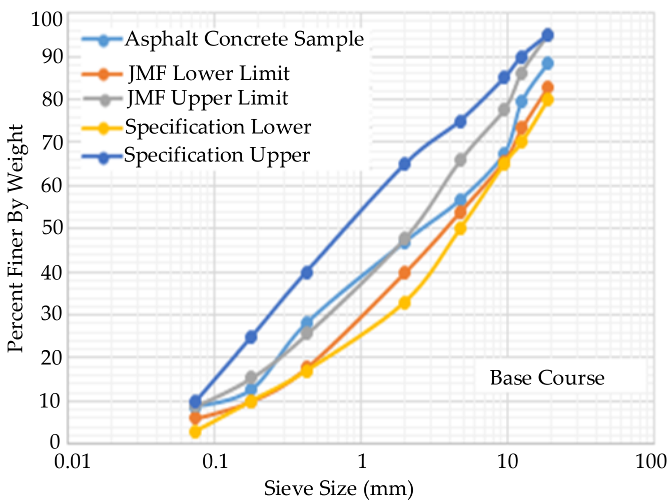


Asphalt Content 5.3 %	**(5-5.5) %**
Marshall Stability 1428 Kg	**(700 kg Minimum)**
Marshall Flow 4.15 mm	**(2-4 mm)**
Voids 3.2%	**(3-7) %**
Voids Filled with Asphalt 79%	**(60-70)**
Fractured Faces 91 %	**(90 % Minimum)**
Specific Gravity 2.415	

Expert System Decision:
Apply cost reduction of 2% due to deviation in the Marshall flow and the Voids filled with Asphalt.

Fig. 2 The output of the expert system for the binder course pavement layer

Figure 3 exhibits the test results of the base course pavement layer. It can be observed that there is a deviation in the gradation at a sieve size of 0.245 mm, and the asphalt content exceeds the requirements. The mixture is not well graded, and the high binder content may exhibit rutting and bleeding. The expert system decided to add an extra 3 cm of binder course material to overcome such deviations.



Asphalt Content 4.8 %	**(4.4-4.6) %**
Marshall Stability 892 Kg	**(520 kg Minimum)**
Marshall Flow 2.7 mm	**(2-5 mm)**
Voids 3.3%	**(3-7) %**
Voids Filled with Asphalt 79%	**(60-70)**

Specific Gravity 2.422

Expert System Decision:

Addition of extra 3 cm of binder course material is required due to deviation in Asphalt content and gradation

Fig. 3 The output of the expert system for the base course pavement layer

5. Conclusion

The developed expert system may be implemented to support the design engineers, the decision-makers, and site engineers in the assessment of the pavement quality. The expert system can propose the remedy to overcome the deviation in the gradation of aggregates, asphalt binder, void content, and mechanical properties of asphalt concrete based on scientific and logical issues rather than the experience of the engineer, which is variable between the decision staff. The system will also help the resident engineer in the decision-making process of accepting or rejecting asphalt concrete pavement material.

Data Availability

Data was shown in the document. If more, the author has data that supports the conclusions.

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