Analytical Method for Asphalt Concrete Job Mix Formula Design

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Abstract - *This paper presents a computerized method for asphalt concrete job-mix formula design; The Excel Solver using Linear Programming by Optimization method was adopted in this paper. The solver can handle problems that involve many variable cells and can help to find combinations of variables that maximize or minimize a target cell. İt also specifies one or more constraints-conditions that must be met for the solution to be valid. It proved that it is efficient and quick enough to be used in such mix design. The aggregate gradation area is calculated from graph by using trapezoidal rule in excel sheet, gradation area is more that area is having more air voids. Gradation aims at reducing the void space, thus improving the performance of the mix.*

Key Words: **Job Mix Formula, Optimization, Excel Solver, Trapezoidal Rule, Gradation Area.**

1. INTRODUCTION

The objective of mix design is to determine the amount of various sizes of mineral aggregates that is used to get a mix of maximum density.

Aggregates are classified as coarse, fine, and filler. The function of the coarse aggregates in contributing to the stability of a bituminous paving mixture is largely due to interlocking and frictional resistance of adjacent particles. Similarly, fines or sand contributes to stability failure function in filling the voids between coarse aggregates. Mineral filler is largely visualized as a void filling agent. Crushed aggregates and sharp sands produce higher stability of the mix when compared with gravel and rounded sands.

Gradation has a profound elect on mix performance. It might be reasonable to believe that the best gradation is one that produces maximum density. This would involve a particle arrangement where smaller particles are packed between larger particles, thus reducing the void space between particles. This creates more particle-to-particle contact, which in bituminous pavements would increase stability and reduce water interaction. However, some minimum amount of void space is necessary to:

- provide adequate volume for the binder to occupy,
- promote rapid drainage, and
- Provide resistance to frost action for base and sub base courses.

The proper selection of different sizes of aggregates to insure better performing mix is known as aggregate blending.

There are several methods available for aggregate blending which can broadly classify into three categories: a) Graphical Methods; b) Trial and Errors and c) Methods which involve Optimization Techniques.

The graphical methods are applied for early stage of asphalt construction and still popular among engineers due to its simplicity and rapidity. Even these methods can be applied in the field to quickly assess the proper aggregate proportioning.

The several popular graphical methods are Triangular Chart Method, Asphalt Institute Method and Routhfutch Method. Graphical methods are limited by number of aggregate sizes. Asphalt Institute graphical method and the triangular chart method cannot accommodate more than two and three sizes of aggregates respectively. The results obtained from the graphical methods are roughly accurate and cannot be directly used. Although graphical methods can be used as an initial tool for aggregate proportioning and the solution obtained can be further optimized by trial and error method. The use of trial and error method also become complex with increases the number of different sizes of aggregates. Also the trial and error methods and graphical methods cannot be used to optimize cost. The aggregate blending problem which affects a large number of aggregates and more than one constraint cannot be solved by trial & error or graphical methods. These complex aggregate blending problems require more accurate and mathematical approach for acceptable results. To address these issues several optimization tools are developed by continuous research in the field. This Paper Presents the Proportioning of Aggregates by Analytical Method i.e., Linear Programming by using EXCEL SOLVER.

2. LITERATURE REVIEW

Saad Issa Sarsam (2015)

The parabola fit using least square method was adopted in this paper; it cares for job mix formula mathematical equation smoothing. The developed program uses parabola fit method to find all possible equations that combines the various material gradations as per the specification requirements, the optimization process will select and print the best six formulas (eq. 1 to eq.6) ascended according to the sum of errors squares. Decision can be made by the user, and given to the computer to choose one of the six equations after considering the economic issue. It is efficient and quick enough to be used in such mix design.

Dr.Talal Hussien Fadhil (2015)

In this research, ten samples had been taken from different text books and papers. Each one contains three types of aggregates; coarse, fine, and filler. The samples were solved individually by seven different methods; five of them by graphical method, the sixth method were solved by running MATLAB and the last method by using Excel sheet. In this research, it has been found that the Equal Distances method would be considered as an accurate, fast, and even easy method, and can be used for any number of aggregate.

Priyansh Singh and Gurpreet Singh Walia (2014)

The aggregates for asphalt mix have to be selected from various stockpiles to match the specified gradation requirements. The fraction of various aggregates which give the desired aggregate gradation is very important to insure quality mix. Previously this fraction is determined by graphical and trial & error method. But due to present need, mix requires more sizes of aggregate which is not computable from these traditional methods. Many optimization techniques are now available which can be used for aggregate blending. These methods can seamlessly use to optimize the either specification requirement or cost minimization or both simultaneously. Here in this paper more scientific and mathematical optimization approaches are presented which can accurately answer these problems.

Khaled A. Kandil and Al-Sayed A. Al-Sobky (2013)

This study investigated the use of a fuzzy triangular membership function to develop a linear program model that can be used to get the optimum aggregate blend. A model was developed to provide the optimum blend taking into consideration: design range, tolerances of mix job formula, and variability associated with the percent passing for each sieve. An experimental investigation was developed to evaluate the variability associated with the percent passing of each sieve to be taken into consideration during model development. Then, the problem of the aggregate blending process was formulated and the main factors affecting this process were discussed.

Mario T. Tabucanon, Pakorn Adulbhan and Stephen S. Y. Chen (1979)

The paper introduces the formulation of a probabilistic programming model to find the optimum mix proportion of aggregates to meet the specific grading requirement in order to minimize the cost which consists of the material cost and the expected penalty cost. The model is probabilistic since the gradation, which is the major parameter, is a random variable. A linear programming model is first formulated. Using the LP solution as initial value, a direct search technique is then employed to solve the problem. The model is expected to be applicable to any problem of aggregates blending. In this paper, however, the mixing aggregates of an asphalt mixing plant are exemplified to test the applicability of the model.

Fouad A. Ahmed (1983)

An approach is developed to determine the area bounded by irregular curves. Two simple formulas are divided to calculate the area in orthogonal and polar coordinate systems. Practical applications show that this technique gives higher accuracy than the conventional methods where offsets are taken at equal intercepts.

Ismat M. Easa Hassan (1987)

This paper develops a generalization of Simpson one-third formula that allows the use of unequal intervals. In this paper evaluated irregular boundary area computation by Simpsons 3/8 rule. The trapezoidal rule and Sampson's rule are the most common methods for computation of the area of irregular boundary. The trapezoidal rule assumes that the irregular boundary is composed of segments of straight lines while Simpsons 1/3 rule assumes parabolic curves. In this paper another approach based on describing the boundary as curves of a third degree polynomial is considered. This leads to Simpsons 3/8 rule for which a general formula is developed to give the total area when offsets at equal intervals dividing the area into a multiple of three sections are measured. Practical tests show that this method can give higher accuracy than the methods mentioned for the same amount of field work.

Simpsons rule:

Area=1/3 d [(first and last/ordinates)+4(sum of even/ordinates)+2(sum off odd/ordinates)].

$$\text{Area}=1/3\, d\, [(y_1+y_n)+4(y_{2+}\, y_{4+} \ldots + y_{n-1})+2(y_{3+}\, y_{5+\ldots\ldots +}\, y_{n-2})$$

The accuracy obtained by Simpsons 3/8 rule is around 1% in both tests. Simpsons 1/3 rule might also give results poorer than those obtained by the trapezoidal rule, as mentioned in the introduction. However, a sketch of the boundary would help t indicate which rule to apply. The work in this paper shows that it is worth considering Simpsons 3/8 rule for area computation since it can provide competitive accuracy.

3. METHODOLOGY ADOPTED

3.1 Aggregate Blending Model:

This Paper Develops a generalization of bituminous mix design for BC Grade-1 as per MORT&H.
The aggregate blending can be performed through number of existing popular methods like trial and error and graphical methods. İn these methods the selection of aggregate blending is becoming complex as the more sizes of aggregates may vary.
The main drawbacks of this process is that a number of trials are required for the selection of different types of aggregate proportions to meet the required gradation range is having a lot of possibilities. İt is time consuming process to achieve all the requirements of aggregate blending.
The Excel Solver can deal with this kind of problem. As the solver can handle problems that involve many variable cells and can help to find combinations of variables that maximize or minimize a target cell. İt also specifies one or more constraints-conditions that must be met for the solution to be valid.
The solution is obtained by a set of equations considering the lower and upper limits of the required gradation as well as the percentage of passing of each type of aggregate.
Let x_1,x_2,x_3,x_4,x_5 represent the different sizes of aggregates used for this mix.
Equation of the form $ax_1+b\,x_2+c\,x_3+d\,x_4+e\,x_5\leq P_l$ or P_u can be written for each sieve size, where a,b,c,d and e passing for that sieve size and P_l and P_u are the upper and lower gradation for that sieve size as per MORT&H specifications.
Solving the above system of equations manually is extremely difficult so, good computer programs are required to solve this. Software like solver in excel yields the solution.

a) Install the "solver" add-in in Excel

i. In the Microsoft Office button, go to excel options to click Add-ins
ii. In the Add-Ins box, select Solver Add-In and click Go...

b) Assign the Variables

X1= 20mm aggregate, X2= 16mm aggregate, X3=10mm aggregate, X4= dust(Robo Sand), X5=filler (Granite Powder).

c) Write the Constraints

$x_1+x_2+x_3+x_4+x_5=1$
$0.26x_1+0.9670x_2+x_3+x_4+x_5\leq 1$
$0.26x_1+0.9670x_2+x_3+x_4+x_5\geq 0.9$
$0.046x_1+0.3640x_2+x_3+x_4+x_5\leq 0.79$
$0.046x_1+0.3640x_2+x_3+x_4+x_5\geq 0.59$
$0.022x_1+0.356x_2+0.93x_3+x_4+x_5\leq 0.72$
$0.022x_1+0.356x_2+0.93x_3+x_4+x_5\geq 0.52$
$0.339x_2+0.1123x_3+0.99x_4+x_5\leq 0.55$
$0.339x_2+0.1123x_3+0.99x_4+x_5\geq 0.35$
$0.172x_3+0.8388x_4+x_5\leq 0.44$
$0.172x_3+0.8388x_4+x_5\geq 0.28$
$0.103x_3+0.6753x_4+x_5\leq 0.34$
$0.103x_3+0.6753x_4+x_5\geq 0.20$
$0.057x_3+0.5490x_4+x_5\leq 0.27$
$0.057x_3+0.5490x_4+x_5\geq 0.15$
$0.3733x_4+x_5\leq 0.20$
$0.3733x_4+x_5\geq 0.10$
$0.1850x_4+x_5\leq 0.13$
$0.1850x_4+x_5\geq 0.05$
$0.860x_4+0.9850x_5\leq 0.08$
$0.860x_4+0.9850x_5\geq 0.02$
$X1\geq 0, X2\geq 0, X3\geq 0, X4\geq 0, X5\geq 0$

d) Write the objective function:
N(x1, x2, x3, x4, x5) = x1 + x2 + x3 + x4 + x5

e) Decision variable cells: D6, F6, H6, J6 and L6.
Construct table from data in problem. How you set up the table is a matter of personal preference.

f) Not in table: the constraint which shows the sum is less than or equal to one.

g) Formulas in cells: Now that the table is set up, we can access the solver. Click on Tools. If you do not see Solver then click on Add-Ins and select Solver. Now click on Tools again and select Solver.

h) Target cell: Minimize cell. To enter it, just click on that cell.

i) Equal to Min

j) Changing Cells: Decision variable cells D6, F6, H6, J6 and L6.

k) Subject to the constraints: Click on Add. Click on Cell Reference and then click in N9, then click on Constraint and then click in P9. Be sure the test listed between them is =. Now click on **Options**.

l) Make sure **Assume Linear Model** and **Assume Non-Negative** boxes are checked, then click OK.
Back at the Solver, click **Solve**. It should yield the solution. Click on Keep solution.

m) The solutions are as shown:
20mm=12.5178%
16mm=22.3287%
10mm=19.685%
Dust=43.4381%
Filler=2.0305%

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
6			x1=		x2=		x3=		x4=		x5=			0		
7																
8			20mm	16mm	10mm	dust	filler				limit					
9		19	0.26	0.967	1	1	1				100			0	=	1
10		19	0.26	0.967	1	1	1				90			0	≤	1
11		13.2	0.046	0.364	1	1	1				79			0	≥	0.9
12		13.2	0.046	0.364	1	1	1				59			0	≤	0.79
13		9.5	0.022	0.356	0.93	1	1				72			0	≥	0.59
14		9.5	0.022	0.356	0.93	1	1				52			0	≤	0.72
15		4.75	0	0.339	0.1123	0.99	1				55			0	≥	0.52
16		4.75	0	0.339	0.1123	0.99	1				35			0	≤	0.55
17		2.36	0	0	0.172	0.8388	1				44			0	≥	0.35
18		2.36	0	0	0.172	0.8388	1				28			0	≤	0.44
19		1.18	0	0	0.103	0.6753	1				34			0	≥	0.28
20		1.18	0	0	0.103	0.6753	1				20			0	≤	0.34
21		0.6	0	0	0.057	0.549	1				27			0	≥	0.2
22		0.6	0	0	0.057	0.549	1				15			0	≤	0.27
23		0.3	0	0	0	0.3733	1				20			0	≥	0.15
24		0.3	0	0	0	0.3733	1				10			0	≤	0.2
25		0.15	0	0	0	0.185	1				13			0	≥	0.1
26		0.15	0	0	0	0.185	1				5			0	≤	0.13
27		0.075	0	0	0	0	0.985				8			0	≥	0.05
28		0.075	0	0	0	0	0.985				2			0	≤	0.08
29														0	≥	0.02
30		Final	1	1	1	1	1				Min			0		

Fig -1: **Decision variable cells**

N30 =C30*D6+D30*F6+E30*H6+F30*J6+G30*L6

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
6		x1=		x2=		x3=		x4=		x5=			0		
7															
8		20mm	16mm	10mm	dust	filler				limit					
9	19	0.26	0.967	1	1	1				100			0	=	1
10	19	0.26	0.967	1	1	1				90			0	≤	1
11	13.2	0.046	0.364	1	1	1				79			0	≥	0.9
12	13.2	0.046	0.364	1	1	1				59			0	≤	0.79
13	9.5	0.022	0.356	0.93	1	1				72			0	≥	0.59
14	9.5	0.022	0.356	0.93	1	1				52			0	≤	0.72
15	4.75	0	0.339	0.1123	0.99	1				55			0	≥	0.52
16	4.75	0	0.339	0.1123	0.99	1				35			0	≤	0.55
17	2.36	0	0	0.172	0.8388	1				44			0	≥	0.35
18	2.36	0	0	0.172	0.8388	1				28			0	≤	
19	1.18	0	0	0.103	0.6753	1				34			0	≥	
20	1.18	0	0	0.103	0.6753	1				20			0	≤	
21	0.6	0	0	0.057	0.549	1				27			0	≥	
22	0.6	0	0	0.057	0.549	1				15			0	≤	
23	0.3	0	0	0	0.3733	1				20			0	≥	
24	0.3	0	0	0	0.3733	1				10			0	≤	
25	0.15	0	0	0	0.185	1				13			0	≥	
26	0.15	0	0	0	0.185	1				5			0	≤	
27	0.075	0	0	0	0	0.985				8			0	≥	
28	0.075	0	0	0	0	0.985				2			0	≤	
29													0	≥	
30	Final	1	1	1	1	1				Min			0		

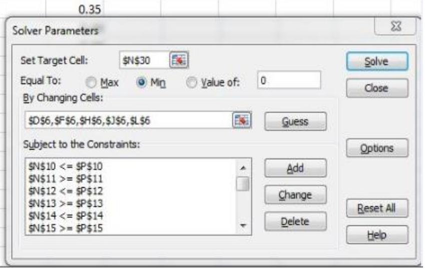

Fig -2: **Target Cell**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
6			x1=	0.125178	x2=	0.223287	x3=	0.19685	x4=	0.434381	x5=	0.020305		1		
7																
8			20mm	16mm	10mm	dust	filler				limit					
9		19	0.26	0.967	1	1	1				100			1	=	1
10		19	0.26	0.967	1	1	1				90			0.9	≤	1
11		13.2	0.046	0.364	1	1	1				79			0.9	≥	0.9
12		13.2	0.046	0.364	1	1	1				59			0.73857	≤	0.79
13		9.5	0.022	0.356	0.93	1	1				72			0.73857	≥	0.59
14		9.5	0.022	0.356	0.93	1	1				52			0.72	≤	0.72
15		4.75	0	0.339	0.1123	0.99	1				55			0.72	≥	0.52
16		4.75	0	0.339	0.1123	0.99	1				35			0.548142	≤	0.55
17		2.36	0	0	0.172	0.8388	1				44			0.548142	≥	0.35
18		2.36	0	0	0.172	0.8388	1				28			0.418521	≤	0.44
19		1.18	0	0	0.103	0.6753	1				34			0.418521	≥	0.28
20		1.18	0	0	0.103	0.6753	1				20			0.333917	≤	0.34
21		0.6	0	0	0.057	0.549	1				27			0.333917	≥	0.2
22		0.6	0	0	0.057	0.549	1				15			0.27	≤	0.27
23		0.3	0	0	0	0.3733	1				20			0.27	≥	0.15
24		0.3	0	0	0	0.3733	1				10			0.182459	≤	0.2
25		0.15	0	0	0	0.185	1				13			0.182459	≥	0.1
26		0.15	0	0	0	0.185	1				5			0.100665	≤	0.13
27		0.075	0	0	0	0	0.985				8			0.100665	≥	0.05
28		0.075	0	0	0	0	0.985				2			0.02	≤	0.08
29														0.02	≥	0.02
30		Final	1	1	1	1	1				Min			1		

Fig -3: **Yielding Solutions**

From this solution we obtain combined gradation. With the values of obtained combined gradation and Required gradation range a graph can be plotted. As shown below.

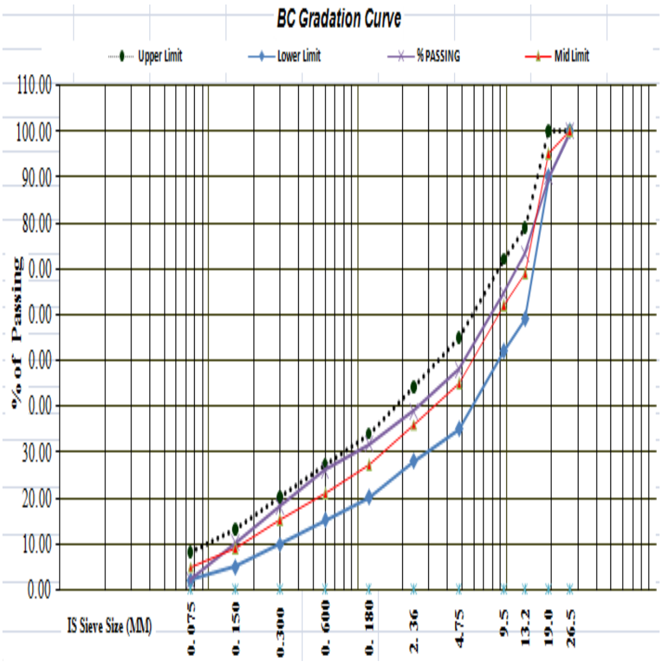

Chart -1: **BC Gradation Curve**

3.2 Aggregate Gradation Area Calculation:

A dense mixture may be obtained by following Fuller's law, which is expressed as: $p = 100^* (d/D)^n$

Where, p is the percent by weight of the total mixture passing any given sieve sized, D is the size of the largest particle in that mixture, and n is the parameter depending on the shape of the aggregate (0.5 for perfectly rounded particles). Based on this law Fuller-Thompson gradation charts were developed by adjusting the parameter n for fineness or coarseness of aggregates.

The Percentage of Passing of Job Mix Formula obtained by using optimizing blending aggregate percentages by Excel Solver.

Table -1. Comparison of Fuller Equation and Obtained gradation by solver

IS Sieve Size(mm)	% Passing MDL	% Passing JMF
26.50	100	100
19.00	86.10	90
13.20	73.08	73.33
9.50	63.03	64.59
4.75	46.14	48
2.36	33.68	38.8
1.18	24.65	31.5
0.60	18.18	25.9
0.30	13.31	18.24
0.15	9.74	10.06
0.075	7.13	2.00

Picking the values from Table 4 we can plot a graph as shown in Figure 3.2.1

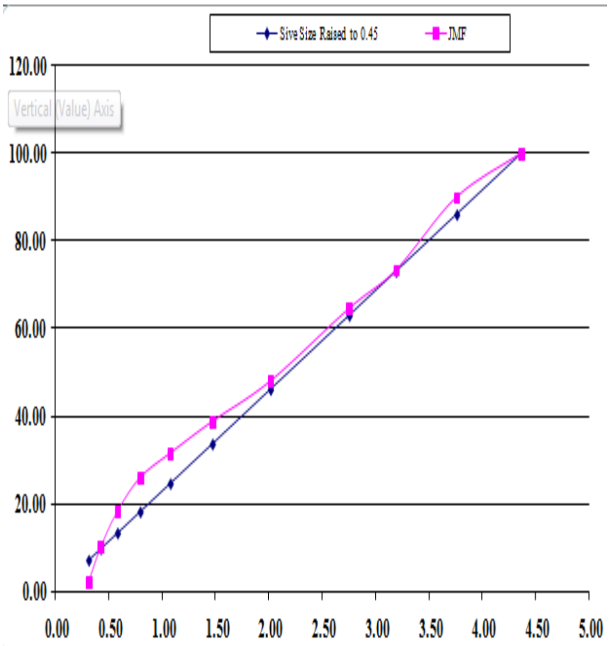

Chart -2: **Gradation Area between JMF & MDL**

The area between Maximum Density Line and Job Mix Formula is calculated by Trapezoidal Rule.

Table -2. Gradation area between JMF&MDL

MDL Area	JMF Area	Gradation Area
0.726	1.0122	0.2862
2.124	1.72875	0.39525
4.6452	3.30645	1.33875
8.3462	6.21035	2.13585
13.72215	11.37435	2.3478
23.87	21.9505	1.9195
41.099	39.84705	1.25195
30.3468	29.9442	0.4026
46.5519	45.3663	1.1856
57.95	56.7605	1.1895

From the Table 2, the Total Aggregate Gradation Area is equal to 12.5. From the aggregate gradation area an opinion on air voids for different aggregate gradations. If Total Gradation area is more it indicates more air voids at different binder contents. By using the model a lot of time is saved as it indicates the occurrence of air voids based upon the area obtained.

4. CONCLUSİON:

The proportioning of aggregate is responsible for good packing and densities. By controlling the aggregate gradation one can improve the mixture performance like resistance to rutting and fatigue. The aggregate blending can be performed through numbers of existing method ranging from trial and errors to more complex computation techniques. The popular methods of aggregate blending involve graphical method, least square method, nonlinear programming, Stimulated Annealing techniques and genetic algorithm etc. In the present scenario every contractor is interested in the cost effective aggregate blend. The old methods are acceptable for rough use or to provide initial solution. But in order to obtain a cost effective blend with satisfactory specification requirement one needs to accommodate more sizes of aggregates. These many constraints cannot be optimized with traditional method. Hence the more accurate and capable tools which can resolve these problems by using Excel solver as discussed in this paper to optimize aggregate blending.

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All the Errors and Omissions are author[1] responsibility alone.

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BIOGRAPHIES

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Research Interests in Roller Compacted Concrete, Porus Concrete, usage of industrial by products for concrete pavement, Modified bitumen, Optimization of concrete and bituminous mixes. Usage of waste Plastic.