

Job Mix Formula for BC Grade-I by Analytic Method Using Excel Solver

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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 GRG Nonlinear 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. It 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.

KEYWORDS: Job Mix Formula, GRG Nonlinear, Excel Solver, Gradation.

I. INTRODUCTION

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 effect 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 GRG Nonlinear method using EXCEL SOLVER.



II. RELATED WORK

The concept of parabola fit using least square method was adopted by Saad Issa Sarsam. [1]. The method uses parabola fit method to find all possible equations that combines the various material gradations as per the specification’s requirements, the optimization process will print six formulas ascended according to the sum of errors squares. In [2] Dr. Talal Hussien Fadhil has taken ten samples from ten 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 by graphical method, the sixth method was solved by using MATLAB, and the last method was solved by using Excel sheet. In this research, it has been found that the equal distance method would be considered as an accurate, fast and even easy method and can be used for any no of aggregates. In [3], Fouad A. Ahmed developed an approach to determine the area bounded by irregular curves. Two simple formulas are dived to calculate the area in orthogonal and polar coordinate system. Practical applications shoe that this technique gives higher accuracy than the conventional method where offsets are taken at equal intercepts. In [4], Khaled A. Kandil and Al-Sobky investigated the use of fuzzy triangular membership functions 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 job mix formula and variability associated with the percent of each sieve. An experimental investigation was developed to evaluate the variability associated with the percent of each sieve to be taken into formulated and the main factors affecting this process were discussed.

III. METHODOLOGY

This Paper Develops a generalization of bituminous mix design for BC Grade-1 as per MORT&H.

Specification of Aggregate Gradation of BC Grade-I as Per MoRT&H

IS SIEVE SIZE (mm)	LOWER LIMIT	MIDDLE LIMIT	UPPER LIMIT
26.5	100	100	100
19	79	89.5	100
13.2	59	69	79
9.5	52	62	72
4.75	35	45	55
2.36	28	36	44
1.18	20	27	34
0.6	15	21	27
0.3	10	15	20
0.15	5	9	13
0.075	2	5	8

Aggregate Blending Model: The aggregate blending can be performed through number of existing popular methods like trial and error and graphical methods. In these methods the selection of aggregate blending is becoming complex as the more sizes of aggregates may vary. The main drawbacks of this process are 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. It 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. It 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 represent the different sizes of aggregates used for this mix.

The Equation of the form $ax_1 + bx_2 + cx_3 + dx_4 \leq P_l$ or P_u can be written for each sieve size, where a, b, c and d 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.



- **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...
- **Assign the Variables**
 $X_1 = 20\text{mm aggregate}$, $X_2 = 12\text{mm aggregate}$, $X_3 = 6\text{mm aggregate}$, $X_4 = \text{dust}$.
- **Write the Constraints:**

$$x_1 + x_2 + x_3 + x_4 = 1$$

$$x_1 + x_2 + x_3 + x_4 \leq 1$$

$$x_1 + x_2 + x_3 + x_4 \geq 1$$

$$0.424x_1 + x_2 + x_3 + x_4 \leq 1$$

$$0.424x_1 + x_2 + x_3 + x_4 \geq 0.79$$

$$0.008x_1 + x_2 + x_3 + x_4 \leq 0.79$$

$$0.008x_1 + x_2 + x_3 + x_4 \geq 0.59$$

$$0.51x_2 + x_3 + x_4 \leq 0.72$$

$$0.51x_2 + x_3 + x_4 \geq 0.52$$

$$0.065x_2 + 0.71x_3 + x_4 \leq 0.55$$

$$0.065x_2 + 0.71x_3 + x_4 \geq 0.35$$

$$0.039x_2 + 0.22x_3 + 0.972x_4 \leq 0.44$$

$$0.039x_2 + 0.22x_3 + 0.972x_4 \geq 0.28$$

$$0.016x_2 + 0.124x_3 + 0.8x_4 \leq 0.34$$

$$0.016x_2 + 0.124x_3 + 0.8x_4 \geq 0.2$$

$$0.004x_2 + 0.098x_3 + 0.6x_4 \leq 0.27$$

$$0.004x_2 + 0.098x_3 + 0.6x_4 \geq 0.15$$

$$0.076x_3 + 0.32x_4 \leq 0.2$$

$$0.076x_3 + 0.32x_4 \geq 0.1$$

$$0.052x_3 + 0.24 \leq 0.13$$

$$0.052x_3 + 0.24x_4 \geq 0.05$$

$$0.03x_3 + 0.14x_4 \leq 0.08$$

$$0.03x_3 + 0.14x_4 \geq 0.02$$
- **Write the objective function:**
 $N(x_1, x_2, x_3, x_4) = x_1 + x_2 + x_3 + x_4$
- **Decision variable cells:** D3, F3, H3 and J3. Construct table from data in problem as shown in (figure1). How you set up the table is a matter of personal preference.
- **Not in table:** the constraint which shows the sum is less than or equal to one.
- **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.
- **Target cell:** Minimize cell. To enter it, just click on that cell (figure2).
- **Equal to Min**
- **Changing Cells:** Decision variable cells D3, F3, H3 and J3.
- **Subject to the constraints:** Click on Add. Click on Cell Reference and then click in N6, then click on Constraint and then click in P6. Be sure the test listed between them is =. Now click on **Options**. Select solving method as **GRG Nonlinear** 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.

The solutions are as shown:

20mm=21.1694%
 12mm=17.8514%
 6mm=24.6193%
 Dust=36.3599%



	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
2															
3		x1	0	x2	0	x3	0	x4	0				0		
4															
5	IS SIEVE SIZE	20mm	12mm	6mm	dust					LIMIT					
6	26.5	1	1	1	1					100			0	≤	1
7	26.5	1	1	1	1					100			0	≥	1
8	19	0.424	1	1	1					100			0	≤	1
9	19	0.424	1	1	1					79			0	≥	0.79
10	13.2	0.008	1	1	1					79			0	≤	0.79
11	13.2	0.008	1	1	1					59			0	≥	0.59
12	9.5	0	0.51	1	1					72			0	≤	0.72
13	9.5	0	0.51	1	1					52			0	≥	0.52
14	4.75	0	0.065	0.71	1					55			0	≤	0.55
15	4.75	0	0.065	0.71	1					35			0	≥	0.35
16	2.36	0	0.039	0.22	0.972					44			0	≤	0.44
17	2.36	0	0.039	0.22	0.972					28			0	≥	0.28
18	1.18	0	0.016	0.124	0.8					34			0	≤	0.34
19	1.18	0	0.016	0.124	0.8					20			0	≥	0.2
20	0.6	0	0.004	0.098	0.6					27			0	≤	0.27
21	0.6	0	0.004	0.098	0.6					15			0	≥	0.15
22	0.3	0	0	0.076	0.32					20			0	≤	0.2
23	0.3	0	0	0.076	0.32					10			0	≥	0.1
24	0.15	0	0	0.052	0.24					13			0	≤	0.13
25	0.15	0	0	0.052	0.24					5			0	≥	0.05
26	0.075	0	0	0.03	0.14					8			0	≤	0.08
27	0.075	0	0	0.03	0.14					2			0	≥	0.02
28															
29	FINAL	1	1	1	1					MIN			0		

Figure 1: Decision variable cells

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
2															
3		x1	0	x2	0	x3	0	x4	0				0		
4															
5	IS SIEVE SIZE	20mm	12mm	6mm	dust					LIMIT					
6	26.5	1	1	1	1					100			0	≤	1
7	26.5	1	1	1	1					100			0	≥	1
8	19	0.424	1	1	1					100			0	≤	1
9	19	0.424	1	1	1					79			0	≥	0.79
10	13.2	0.008	1	1	1					79			0	≤	0.79
11	13.2	0.008	1	1	1					59			0	≥	0.59
12	9.5	0	0.51	1	1					72			0	≤	0.72
13	9.5	0	0.51	1	1					52			0	≥	0.52
14	4.75	0	0.065	0.71	1					55			0	≤	0.55
15	4.75	0	0.065	0.71	1					35			0	≥	0.35
16	2.36	0	0.039	0.22	0.972					44			0	≤	0.44
17	2.36	0	0.039	0.22	0.972					28			0	≥	0.28
18	1.18	0	0.016	0.124	0.8					34			0	≤	0.34
19	1.18	0	0.016	0.124	0.8					20			0	≥	0.2
20	0.6	0	0.004	0.098	0.6					27			0	≤	0.27
21	0.6	0	0.004	0.098	0.6					15			0	≥	0.15
22	0.3	0	0	0.076	0.32					20			0	≤	0.2
23	0.3	0	0	0.076	0.32					10			0	≥	0.1
24	0.15	0	0	0.052	0.24					13			0	≤	0.13
25	0.15	0	0	0.052	0.24					5			0	≥	0.05
26	0.075	0	0	0.03	0.14					8			0	≤	0.08
27	0.075	0	0	0.03	0.14					2			0	≥	0.02
28															
29	FINAL	1	1	1	1					MIN			0		

Figure 2: Target cell



Solver Parameters

Set Objective:

To: Max Min Value Of:

By Changing Variable Cells:

Subject to the Constraints:

- <=
- >=
- <=
- >=
- <=
- >=
- <=
- >=
- <=
- >=
- <=

Make Unconstrained Variables Non-Negative

Select a Solving Method:

Solving Method
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

IV. EXPERIMENTAL RESULTS

The aggregate gradation of BC Grade – I is calculated by analytic method is tabulated below in (figure3)
The results of mix design of BC Grade – I and the solution of gradation is:

- x1 = 21.1694%
- x2 = 17.8514%
- x3 = 24.6193%
- x4 = 36.3599%

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
2															
3		x1	0.211694	x2	0.178514	x3	0.246193	x4	0.363599				1		
4															
5	IS SIEVE SIZE	20mm	12mm	6mm	dust					LIMIT					
6	26.5	1	1	1	1					100			1	≤	1
7	26.5	1	1	1	1					100			1	≥	1
8	19	0.424	1	1	1					100			0.878065	≤	1
9	19	0.424	1	1	1					79			0.878065	≥	0.79
10	13.2	0.008	1	1	1					79			0.79	≤	0.79
11	13.2	0.008	1	1	1					59			0.788306	≥	0.59
12	9.5	0	0.51	1	1					72			0.700835	≤	0.72
13	9.5	0	0.51	1	1					52			0.700835	≥	0.52
14	4.75	0	0.065	0.71	1					55			0.55	≤	0.55
15	4.75	0	0.065	0.71	1					35			0.55	≥	0.35
16	2.36	0	0.039	0.22	0.972					44			0.414543	≤	0.44
17	2.36	0	0.039	0.22	0.972					28			0.414543	≥	0.28
18	1.18	0	0.016	0.124	0.8					34			0.324264	≤	0.34
19	1.18	0	0.016	0.124	0.8					20			0.324264	≥	0.2
20	0.6	0	0.004	0.098	0.6					27			0.243001	≤	0.27
21	0.6	0	0.004	0.098	0.6					15			0.243001	≥	0.15
22	0.3	0	0	0.076	0.32					20			0.135063	≤	0.2
23	0.3	0	0	0.076	0.32					10			0.135063	≥	0.1
24	0.15	0	0	0.052	0.24					13			0.100066	≤	0.13
25	0.15	0	0	0.052	0.24					5			0.100066	≥	0.05
26	0.075	0	0	0.03	0.14					8			0.05829	≤	0.08
27	0.075	0	0	0.03	0.14					2			0.05829	≥	0.02
28															
29	FINAL	1	1	1	1					MIN			1		

Figure 3: Yielding solutions

V. CONCLUSION

- 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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