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ABSTRACT

The Federal Highway Administration (FHWA) Demonstration Project No. 74 has clearly shown that significant differences exist between the volumetric properties of the laboratory designed and plant produced hot mix asphalt (HMA) mixes. The volumetric properties include voids in the mineral aggregate (VMA) and the voids in the total mix (VTM). This project was undertaken to develop practical guidelines for the HMA contractors to reconcile these differences thereby assisting them to consistently produce high quality HMA mixes. The HMA mix design and field test data from 24 FHWA demonstration projects were entered into a database. The data included mix composition (asphalt content and gradation) and volumetric properties. The data were analyzed to identify and, if possible, quantify the independent variables (such as asphalt content and the percentages of material passing No. 200 and other sieves) significantly affecting the dependent variables (such as VMA and VTM).

Based on the preceding work, troubleshooting charts have been constructed to correct and reconcile differences between the volumetric properties of the job mix formula and the produced mix.

KEYWORDS: hot mix asphalt, asphalt concrete, asphalt paving mixtures, field management, volumetric properties, quality control, quality assurance, air voids, VMA

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INTRODUCTION

Demonstration Project No. 74, “Field Management of Asphalt Mixes” initiated by Federal Highway Administration studied 17 mixes from 15 State Highway Agency (SHA) paving projects [1]. Of the 17 mixes, there were only two mixes where the actual production met the mix design targets. Ten mixes should have been modified during production while five mixes should have been totally redesigned. The Demonstration Project confirmed that current laboratory mix design procedures do not represent actual mix production. Flawless laboratory-designed mixes can incur mix-related problems during production which can lead to premature pavement deterioration. Field management of hot mix asphalt (HMA) provides a viable tool to identify the differences between plant produced and laboratory designed HMA mixes and effectively reconcile these differences [2].

Demonstration Project No. 74 concluded that a field mix verification of the material produced at the HMA plant should be included as a second phase in the design process. Mix verification is defined as the validation of a mix design within the first several hundred tons of production . The void properties established from mix verification proved to be an effective tool in identifying mix production variations or any differences between plant produced and laboratory designed HMA mixes. However, the measures recommended in the project to correct the identified problems were somewhat generalized. It was recommended that the job mix formula (JMF) should be adjusted to make the gradation more uniform and/or move the gradation away from the maximum density line. It was also noted that (1) gap-graded mixes and mixes which plot close to the maximum density line are generally sensitive mixes, and (2) mixes with a hump near the No. 30 sieve are generally tender mixes.

A significant amount of data has been collected by Demonstration Project No. 74. Analysis of these data could yield more practical guidelines to reconcile differences between plant produced and laboratory designed HMA mixes.

OBJECTIVE

The objective of this project was to develop practical guidelines to reconcile differences between plant produced and laboratory designed HMA mixes. This has been achieved by analyzing the data collected by the Demonstration Project No 74, and identifying and quantifying independent variables which significantly affect the void properties (dependent variables) of the produced mix.

The above objective has been accomplished by completing the following tasks:

Task 1 - Preparation of data base
Task 2 - Analysis of data
Task 3 - Method for reconciling differences between mix design and production
Task 4 - Field verification of proposed method of reconciliation

TASK 1: PREPARATION OF DATA BASE

Twenty four Demonstration Project No. 74 reports were obtained from the Federal Highway Administration (FHWA). A total of 26 asphalt mixes were used in these 24 demonstration projects. These vast amounts of data contained in these reports were grouped into three major groups and entered into a data base.

The first data group contains information about the HMA plant such as plant type, production rate, dust collection system, and type of mix storage system. Of the 24 demonstration projects, 19 projects used drum mix plants and five projects used batch mix plants. Baghouse dust collection system was used in 17 projects, wet scrubber was used in five projects, and cyclone dust collection system was used in two projects.

The second data group contains information about the 26 HMA mixtures used on the 24 demonstration projects such as mix type, maximum nominal aggregate size, amount of natural sand, coarse aggregate type, fine aggregate type, Los Angeles abrasion loss, sand equivalent value, percent hydrated lime, and percent reclaimed asphalt pavement (RAP) used. Thirteen mixes were used in surface course, six in binder course, and two in base course. The use of five mixes is not known. Four mixes had 9.5 mm (3/8 inch) maximum nominal size. Eleven mixes had 12.5 mm (½ inch) maximum nominal size. Nine mixes had 19 mm (3/4 inch) maximum nominal size. Two mixes had 25.4 mm (1 inch) maximum nominal size. Seven mixes contained natural sand. Seven mixes contained hydrated lime, and four mixes contained RAP.

The third data group contains information about the asphalt content, void properties, and aggregate gradation specified by (a) mix design, (b) obtained from the verification process, and (c) obtained during production. Basically, production data has been analyzed rigorously to identify and quantify independent variables which significantly affect the void properties of the produced mix. The following information, if available, is contained in the third data group: (a) asphalt content and void properties of JMF, verification, and production, (b) aggregate gradation of JMF, verification, and production, and (c) the location of aggregate gradation curve at the time of production with respect to the maximum density line (MDL). The MDL was established according to Superpave Level 1 mix design procedures. The location of aggregate gradation during production can be summarized as follows: 15 mixes were "above" MDL, two mixes were "slightly above" MDL, five mixes were "on" MDL, three mixes were "slightly below" MDL, and one mix was "below" MDL. It was observed that design gradations and production gradations were generally different. Production gradations more accurately represent the aggregate gradation for the project. Therefore, the maximum nominal size and maximum size of the aggregate for the project have been based on the production gradation rather than the JMF gradation for entry into the database.

It was believed at the beginning of the project that void properties may be affected differently in surface and base/binder mixes during production because of differences in the maximum aggregate sizes, gradations, and asphalt contents. To investigate and detect such effects, the date base was split into "surface" and "base/binder" mixes. "Surface" mix is the mix with maximum nominal aggregate size equal to or less than 12.5 mm (½ inch) and "Base/Binder" mix is the mix with maximum nominal aggregate size more than 12.5 mm (½ inch). The relationship between the independent variables and voids in mineral aggregate (VMA) and voids in total mix (VTM) was analyzed for each mix type. No significant differences in relationship were found between these two mix types. Therefore, the data base was combined for subsequent analyses.

TASK 2: ANALYSIS OF DATA

The focus of this project are VMA and VTM of the HMA mix produced in the asphalt plant. It is therefore necessary to identify those factors that (1) can be controlled easily at the HMA plant and (2) have a significant effect on VMA and VTM of the produced mix. Therefore, VMA and VTM were chosen as dependent variables. The independent variables are those factors that can generally be controlled at the HMA plant. Independent variables were asphalt content and percentages passing the #200, #100, #50, #30, #16, #8, #4, 9.5 mm, 12.5 mm, 19 mm, 25 mm, and 37.5 mm sieves.

The objective of this task is to identify which independent variables are the best predictor of the void properties such as VMA and VTM. The identified best predictors can then be used to reconcile differences between mix design and production in the next task. Two techniques were used to identify the best predictive variables: linear regression and stepwise multi-variable regression. Single and multi variables predictive models were then constructed with the best predictive variables.

Linear Regression -- The coefficient of correlation (R value) generated by the linear regression gives a measure of how well the independent variable is correlated to the dependent variable. In the linear regression analysis, all independent variables were individually correlated to the dependent variable for each project. The R values of the independent variables for each project are given elsewhere [3]. A broad range of R values from 0.00 to 0.96 were generated. These R values can be used directly to rank the independent variables in each project but it is more desirable to rank the independent variable based on all projects. Therefore, the R values for each independent variable based on the averaged R values is given in Table 1. The averaged R value does not have any specific statistical meaning. It is used only as a tool to rank the independent variables for all projects. The following observations are made based on Table 1:

1. With respect to VMA, the top five independent variables are the percentages of aggregate passing #8, #16, #30 and #50 sieves, and asphalt content. This indicates that the relative proportions of coarse and fine aggregates are very important and can be used to adjust the VMA.
2. With respect to VTM, the top ranking variable is the asphalt content, followed by the percentages of aggregate passing #30, #50, #100 and #200 sieves. This indicates that the VTM is also a function of VMA which is controlled by the relative proportions of coarse and fine aggregate as mentioned above.

Table 1. Averaged R Values and Combined Rankings of Independent Variables

Variable	All Projects				High Variability Projects			
	VMA		VTM		VMA		VTM	
	R (Average)	Ranking	R (Average)	Ranking	R (Average)	Ranking	R (Average)	Ranking
Asphalt Content	0.333	4	0.401	1	0.263	8	0.479	1
#200	0.301	9	0.300	4	0.407	4	0.361	3
#100	0.294	10	0.301	3	0.406	5	0.354	5
#50	0.331	5	0.283	5	0.472	2	0.356	4
#30	0.372	1	0.302	2	0.483	1	0.384	2
#16	0.347	2	0.268	6	0.449	3	0.328	6
#8	0.345	3	0.247	7	0.381	6	0.298	7
#4	0.316	6	0.199	10	0.300	7	0.229	9
9.5 mm	0.314	7	0.214	8	0.261	9	0.238	8
12.5 mm	0.304	8	0.214	9	0.252	10	0.192	10

The combined rankings from all projects were not completely adequate in identifying important variables affecting VMA but were somewhat able to identify the important variables affecting VTM during production. The preceding analysis was impeded by including high quality control projects which had low variation in VMA and VTM resulting in clustered data points. The FHWA examined the test data from 17 paving projects in a previous study and found that the pooled mean VMA standard deviation was 0.47 and the mean VTM standard deviation was 0.66 [1]. Therefore, projects with VMA standard deviation less than 0.47 and VTM standard deviation less than 0.66 were then excluded to increase the sensitivity of the preceding analysis. Twelve projects were excluded from the VMA analysis and ten projects were excluded from the VTM analysis. Table l also tabulates the averaged R value and combined rankings for the selected high variability projects. The following observations are made.

1. With respect to VMA, the top six ranking variables consist of mix gradation passing #8, #16, #30, #50, #100, and #200 sieves. This means that the relative proportion of the fine aggregate in the mix and the amount of material passing #200 (P200) sieve are very important in affecting the VMA. However, the percentage of material passing #30 and #50 sieves have the highest rankings. These percentages are generally influenced by the presence and amount of natural sand in the mix.
2. With respect to VTM, the top ranking variable is the asphalt content followed by the aggregate gradation passing #16 and finer sieves. Again, it indicates the dependence of VTM on VMA which was also affected by these sizes. The P200 material ranked third and, therefore, is considered important.

Stepwise Multi-Variable Regression -- A Forward Selection Procedure is available in the SAS program [4] to determine which independent variables are closely related to VMA and VTM. The selection procedure begins by finding the variable that produces the optimum (highest R^2) one-variable model. In the second step, the procedure finds the variable that, when added to the already chosen variable, results in the largest reduction in the residual sum of squares (highest R^2 value). The third step finds the variable that, when added to the model provides a reduction in sum of squares considered statistically significant at a specified level. The output of the Forward Selection Procedure for each project (including partial R^2 values for each independent variable is given elsewhere [3]. The R^2 value for each project as generated by the Forward Selection Procedure ranged from 0.24 to 0.99.

There are two possible methods to rank the independent variables in each project from the Forward Selection Procedure output. The first ranking method (Method 1) is according to the order they were selected by the Forward Selection Procedure. The second method (Method 2) is to rank the independent variables according to their partial R^2 values. As mentioned in Linear Regression, it is desirable to rank the independent variables based on all projects rather than each individual project. To obtain a combined ranking for all projects using Method 1, the first variable selected is assigned 1 point, the second variable selected is assigned 2 points and so on. A combined ranking is then possible by averaging the assigned points for all projects. For the second ranking method (Method 2), the partial R^2 values of each independent variable were averaged over all projects. A combined ranking is then possible based on the averaged partial R^2 value. The averaged partial R^2 values do not have any specific statistical meaning except to be used as a tool to rank the independent variables.

Table 2 summarizes the combined rankings for selected projects with relatively -lower quality control (standard deviation more than 0.47 for VMA and more than 0.66 for VTM) using Methods 1 and 2. The combined ranking obtained by both methods are similar to those obtained by correlation analysis (Table 1). However, the combined ranking by Method 2 shows better resemblance with the combined ranking by correlation analysis than Method 1. Intuitively, Method 2 being rational seems to be a better approach for quantitative analysis than Method 1 and thus obtaining a combined ranking of the independent variables.

Table 2. Combined Rankings of Independent Variables Using Forward Selection Procedures Methods 1 and 2 (High Variability Projects)

Variable	Method 1				Method 2			
	VMA		VTM		VMA		VTM	
	Avg. Point	Ranking	Avg. Point	Ranking	Avg.)R^2	Ranking	Avg.)R^2	Ranking
Asphalt Content	6.07	8	2.00	1	0.032	8	0.219	1
#200	4.86	2	5.23	3	0.068	6	0.110	2
#100	3.92	1	5.07	2	0.149	1	0.097	3
#50	5.08	3	5.27	4	0.103	4	0.076	5
#30	5.93	7	5.87	6	0.084	5	0.028	8
#16	5.54	5	5.57	5	0.136	3	0.060	6
#8	5.62	6	6.85	10	0.143	2	0.035	7
#4	5.39	4	6.06	8	0.031	9	0.020	9
9.5 mm	7.36	10	6.00	7	0.028	10	0.080	4
12.5 mm	6.25	9	6.14	9	0.038	7	0.018	10

<u>Best Predictive Variables</u> -- The best predictive variables selected by linear regression analysis (R value), and Forward Selection Procedure Method 1 (Point Value), and Forward Selection Procedure Method 2 ()R^2 value) are shown in Table 3. The statistical analyses include the projects with high standard deviations for VMA and VTM, as mentioned earlier. Both techniques, linear regression analysis and Forward Selection Procedure, used to select the best predictive variables have their own inadequacy. The linear regression evaluates a single variable, while Forward Selection Procedure can evaluate several variables. However, each analysis does provide a useful suggestion as to which variable has the best predictive power. The following observations are made based on the combined ranking data (given in Table 3) from these ranking analyses.

1. The best practical predictive independent variables for VMA are the #8, #16, #30, #50, #100, and #200 sieves. In other words, the relative proportion of the fine aggregate and the amount of material passing #200 sieve is important.
2. The best practical predictive variables for VTM are asphalt content (AC) and #200 sieve, followed by #8, #16, #30, #50, and #100 sieves.

There seems to be reasonable rationale to support the result of the analysis. It is generally accepted that VTM is most significantly affected by AC. VTM and VMA are also significantly affected by the percentage of material passing the #200 (P200) sieve which fills the spaces between aggregate particles. In addition, it is generally believed that the amount of fine aggregate (percent passing #8) has an effect on VMA and VTM. Generally, an increase in percent passing the #8 sieve (fine aggregate) also increases the percent passing the smaller sieve sizes (#16, #30, #50, #100, #200). The higher rankings received by the #30 and #50 sieves seem to reflect the effect of natural sand in HMA mixes.

Table 3. Results of Ranking Analysis by Three Methods

	Combined Ranking Using		
Combined Ranking	R value (Average)	Point Value (Average)	)R^2 (Average)
VMA			
1	#30	#100	#100
2	#50	#200	#8
3	#16	#50	#16
4	#200	#4	#50
5	#100	#16	#30
6	#8	#8	#200
VTM			
1	AC	AC	AC
2	#30	#100	#200
3	#200	#200	#100
4	#50	#50	3/8
5	#100	#16	#50
6	#16	#30	#16
7	#8	3/8	#8

TASK 3: METHOD FOR RECONCILING DIFFERENCES BETWEEN MIX DESIGN AND PRODUCTION

The objective of this project was to develop guidelines to reconcile differences between mix design and production. The guidelines must be practical and applicable within the confine of practical asphalt plant operation. It was determined in Task 2 that the best predictive variables for VMA are the #200, #100, #50, #30, #16, and #8 sieve and the best predictive variables for VTM are asphalt content, #200, #100, #50, #30,#16, and #8, sieve. Asphalt content and, in some cases, #200 sieve can be independently controlled and adjusted to reconcile differences between produced and laboratory designed HMA mixes. However, the other sieve sizes (#100, #50, #30, #16, #8) cannot be controlled independently because they are related to the proportion of coarse or fine aggregate. Increasing the fine aggregate portion will increase the amount of material passing all the sieve sizes (#200, #100, #50, #30, #16, #8), and the magnitude of increase will depend largely on the gradation of the fine aggregate. Since the finer sieve sizes are inter-related, it is recommended that the finer sieve sizes should be combined as one predictive variable (that is the amount of fine aggregate) rather than six (6) individual predictive variables.

For practical reasons, attempts to reconcile differences between mix design's VMA and productions's VMA should be achieved by first adjusting the amount of P200 material and then, if necessary, by adjusting the other sieve sizes by changing the amount of fine aggregate. Attempts to reconcile differences between mix design's VTM and production's VTM should be achieved by first adjusting the amount of P200 material if it deviates significantly from the JMF. The P200 material can be adjusted by controlling the amount of dust returned from dust collection system. The second step, if necessary, is to adjust the asphalt content. Finally, it may be necessary, to adjust the amount of material passing other sieve sizes (the amount of fine aggregate) which practically amounts to redesigning the mix.

The following are regression models which relate VMA and VTM to the best predictive variables. These models estimate the magnitude of adjustment needed to reconcile the differences between mix design and production.

VMA Regression Models -- The regression model recommended to predict the effect of the material passing #200 sieve (P200) on VMA is given as:

$$\Delta VMA = \beta_1 \times \Delta P200 \qquad (1)$$

where,
) VMA = difference from project VMA
) P200 = difference from project P200

Regression analysis was performed on projects with high VMA variation (***** more than 0.47) to increase the sensitivity of the regression model. These projects were then divided into three groups based on their VMA levels (> 16%, 14-16%, and < 14%) and analyzed separately. The results of the analyses are shown in Table 4.

Table 4 shows that VMA is expected to decrease when the P200 material is increased (based on the negative value of $\mathbf{\$}_1$). The VMA of the mixes in high VMA range is expected to decrease more than mixes in the low VMA range. Overall, for every percent increase in P200 material, VMA is expected to decrease by an average of about 0.3 percent.

Table 4. Changes in VMA Caused by Changes in P200 Sieve

Analysis	Projects Analyzed	$\mathbf{\$}_1$	R^2
1	Projects with $\mathbf{F}_{VMA}>0.47$	-0.3103	0.1242
2	Projects with $\mathbf{F}_{VMA}>0.47$ and VMA>16%	-0.3723	0.1385
3	Projects with $\mathbf{F}_{VMA}>0.47$ and 14%<VMA>16%	-0.3339	0.1267
4	Projects with $\mathbf{F}_{VMA}>0.47$ and VMA<14%	-0.2543	0.1177

The fine sieve sizes (#200, #100, #50, #30, #16, #8) were combined to produce another predictive variable, Area Enclosed. Area Enclosed is defined as the area enclosed by the aggregate gradation and the MDL from #8 sieve down to #200 sieve. An example of how the variable Area Enclosed is calculated and the associated regression model are given elsewhere [3]. The relationship between VMA and Area Enclosed was found to be very dependent on the presence or absence of natural sand in the HMA mixes. A decrease in the Area Enclosed increased the VMA of mixes with natural sand. Since the aggregate gradation of mixes with natural sand are generally above the MDL (at #16, #30, and #50 sieves), reducing the amount of natural sand in these mixes decreases the Area Enclosed and thus increases the VMA. This is logical because generally sand particles are round, pack densely and, therefore, decrease the VMA.

An increase in the Area Enclosed increased the VMA of mixes with no natural sand. If the gradation is above the MDL, increasing the amount of fine aggregate increases the Area Enclosed. For gradation below the MDL, decreasing the amount of fine aggregate also increases the Area Enclosed. In both cases, when the aggregate gradation deviates from the MDL, it increases the Area Enclosed and, therefore, the VMA.

The average slope $\$_1$ of Equation 1 (Table 4) is relatively flat, about 0.3. As mentioned earlier, adjusting the P200 material by one percent caused an average of 0.3 percent change in VMA. Therefore, the P200 adjustment can be used if the VMA correction to be made is minor. HMA mixes that need a significant amount of VMA correction have to be adjusted by varying the coarse-fine aggregate proportions (Area Enclosed). Consequently, it is recommended that adjusting the P200 is more appropriate for fine tuning the VMA while changing the aggregate gradation by adjusting the coarse-fine aggregate proportion (Area Enclosed) is more suitable for larger changes in VMA. Since the required adjustments are mix specific no quantifiable change in coarse-fine aggregate proportion can be recommended other than directional changes (increase or decrease coarse-fine aggregate proportion).

<u>VTM Regression Models</u> -- There is a strong relationship between VTM and VMA. All VTM regression models, therefore, will have VMA terms as predictive variables. Also, all predictive variables for VMA are also applicable to VTM. The best regression model which relates VTM to P200 is given as:

$$VTM = -8.3932 + 0.8793(VMA) + 0.9632(P200) - 0.07579(VMA)(P200) \qquad (2)$$

$$R^2 = 0.42$$

Differentiating Equation 2 with respect to P200 results in:

$$\frac{\Delta VTM}{\Delta P200} = 0.9632 - 0.07579(VMA) \qquad (3)$$

Equation 3 shows that the effect of P200 on VTM is dependent on VMA. Table 5 which is based on Equation 3 shows VTM is expected to decrease when the P200 is increased (negative value of Equation 3). The VTM of mixes with high VMA is expected to decrease more than mixes with low VMA. Table 5 deceptively shows that the VTM increases with the increase in P200 for mixes with 12 percent VMA. This has been caused by insufficient data points in the low VMA region to generate a reliable model.

Table 5. Changes in VTM Caused by Changes in P200 at Different VMA Level

VMA	12%	13%	14%	15%	16%	17%	18%
)VTM/)P200	0.054	-0.022	-0.098	-0.174	-0.249	-0.325	-0.401

The best regression model to relate asphalt content (AC) to VTM is given as:

$$VTM = 8.7802 - 3.0552(AC) + 0.1420(AC)(VMA) \qquad (4)$$

$$R^2 = 0.63$$

Differentiating Equation 4 with respect to asphalt content results in:

$$\frac{\Delta VTM}{\Delta AC} = -3.0552 + 0.1420\ (VMA) \qquad (5)$$

Equation 5 shows that the effect of asphalt content on VTM is also dependent on VMA. Table 6 which is based on Equation 5 shows that an increase in asphalt content decreases the VTM (negative value of Equation 5). This decrease is more severe for mixes with lower VMA.

No statistically satisfying model to predict VTM using the variable Area Enclosed could be constructed. However, increasing the Area Enclosed (deviating from the maximum density line or MDL) will increase the VTM of mixes with no natural sand but decrease the VTM of mixes with natural sand. Natural sands usually make the HMA mixes over sanded (too much deviation from the MDL and therefore, increased Area Enclosed) and tend to have relatively low VMA because natural sand particles pack densely. This change in VTM, therefore, reflects the change in VMA.

The slope values in Table 5 are comparatively smaller than the slope values in Table 6. Adjusting the P200, especially if it is excessively higher than the JMF, is more appropriate for fine tuning the VTM. Adjusting the asphalt content is more suitable for larger changes in VTM. It is expected that Equation 3 (or Table 5) will be used first, if the P200 deviates from the JMF, in any attempts to reconcile differences in mix design's VTM and production's VTM. If the production P200 is reasonably close to the JMF P200, the asphalt content should be adjusted.

Table 6. Changes in VTM Caused by Changes in AC at Different VMA Level

VMA	12%	13%	14%	15%	16%	17%	18%
ΔVTM/ ΔAC	-1.351	-1.209	-1.067	-0.925	-0.783	-0.641	-0.499

<u>Steps Recommended to Reconcile Differences between Mix Design and Production</u> -- The values tabulated in Tables 4, 5 and 6 are derived from different mixes and thus represent average values for these mixes. Since each mix is unique, the values presented here may not accurately predict its behavior.

Figure 1 is a flow chart which shows the recommended steps to reconcile differences between mix design's VMA and mix production's VMA, after it has been verified that the composition (asphalt content and gradation) of the produced mix is reasonably close to that of the designed mix (JMF).

If the composition of the produced mix meets the JMF and the VMA of the produced mix has a minor deviation (less than 0.3%) from the JMF, it has been suggested to adjust the amount of P200 material in the mix. A one percent decrease in the P200 material to cause an average increase of 0.3 percent in the VMA, can be used as an approximate guide to determine the quantitative adjustment required for the P200 material to effect the desired change in VMA value. As an alternate, an extended laboratory mix design can include using two additional P200 contents (JMF ± 2%) in the HMA mix and plotting the curve of P200 content versus VMA. The percent decrease in VMA from the corresponding increase in the P200 content (which is mix specific) can be obtained from this curve and is likely to be more accurate than the approximate guide mentioned above.

If the VMA of the produced mix has a major deviation (more than 0.3%) from the JMF, the flow chart recommends different approaches depending on whether the HMA mix contains natural sand or not. If the HMA mix contains natural sand, the amount of natural sand will need to be decreased

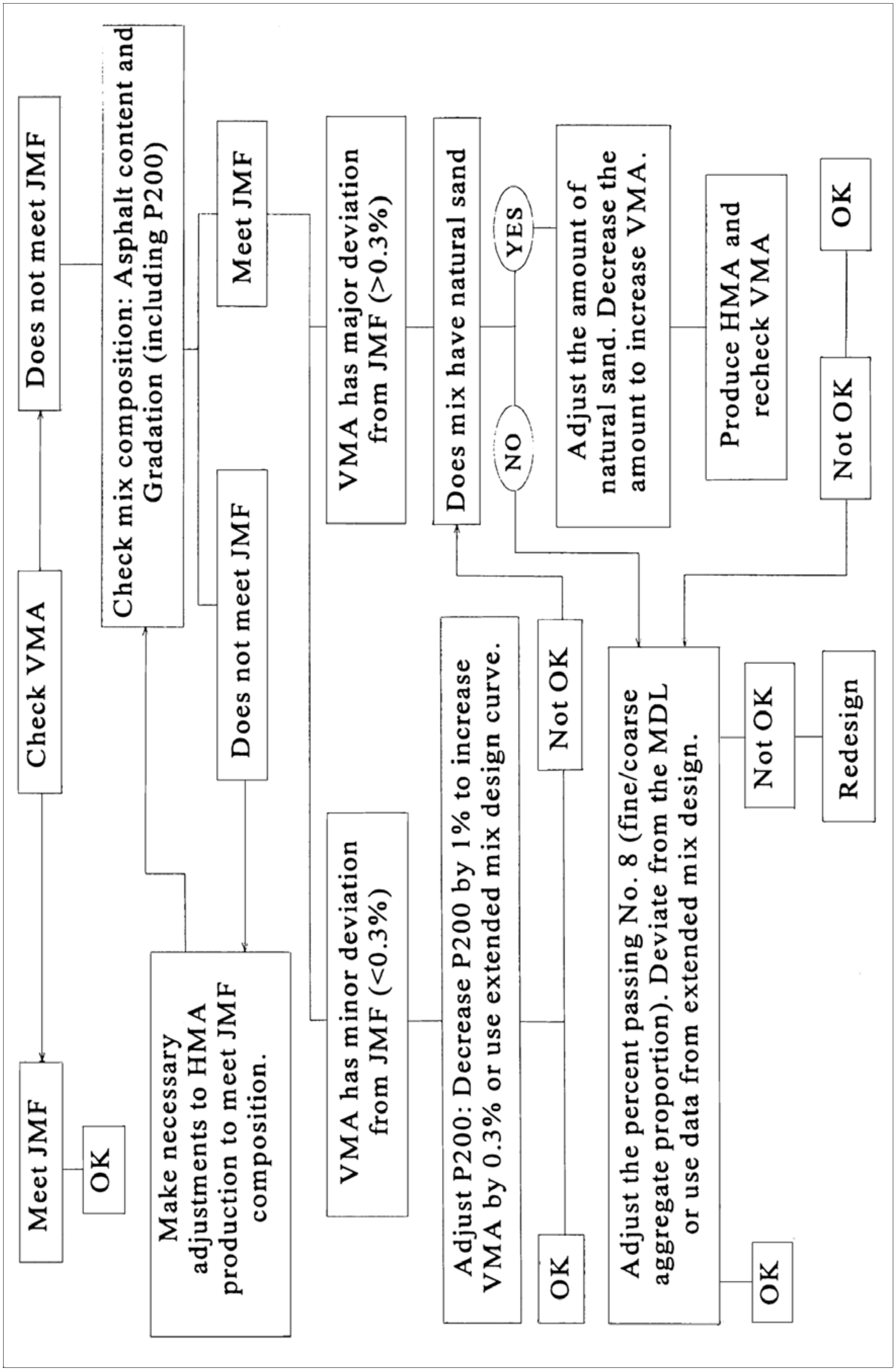

Figure 1. Flow Chart for Reconciling VMA

to increase VMA. If the HMA mix does not contain natural sand, the percentage of material passing the #8 sieve (that is, the relative proportions of coarse and fine aggregates) will need to be adjusted to move away from the maximum density line (MDL). Since this adjustment is mix specific, no quantitative recommendations can be made. However, an extended laboratory mix design which includes two additional percentages of the material passing #8 sieve (JMF ± 5%) is likely to be very helpful. The design curve obtained by plotting these percentages of passing #8 sieve versus VMA can indicate the quantitative adjustment needed to the #8 sieve to obtain desired VMA.

If the production VMA is not reconciled after the preceding efforts, the entire mix will need to be redesigned by changing the mix components and/or their proportions.

After the production VMA is reconciled, the next step is to check the VTM. Figure 2 is a flow chart to reconcile differences between mix design's VTM and production's VTM. Again, it is assumed that the produced mix has composition (asphalt content and gradation) close to the JMF composition. If the VTM has a minor deviation (less than 0.5%) from the JMF, it is recommended to adjust the P200 material. The P200 material will need to be deycreased to increase the VTM. Table A (inside Figure 2) can be used as an approximate guide to determine the quantitative adjustment required to the P200 material to obtain the desired VTM. As an alternate, the extended laboratory mix design (mentioned earlier) curve of percent P200 versus VTM can be used for quantitative adjustment. If the VTM has a major deviation from the JMF (> 0.5%), it is recommended to adjust the asphalt content. The asphalt content will need to be decreased to increase the VTM. Table A (inside Figure 2) can be used as an approximate guide to determine the quantitative adjustment required for the asphalt content to effect the desired change in VTM. A better alternative is to use the asphalt content versus VTM curve developed during the routine laboratory mix design. The slope of this curve can give an indication of the quantitative adjustment needed to asphalt content.

TASK 4: FIELD VERIFICATION OF PROPOSED METHOD OF RECONCILIATION

It was deemed necessary to verify the proposed method of reconciling laboratory designed mix with the plant produced mix in the field. A paving project which was due to be visited by the FHWA trailer, was selected during the 1994 construction season. The HMA mix produced by the asphalt plant was a base mix with a maximum nominal size of 25 mm (1 inch). The details of this paving project such as JMF and production data (including volumetrics) are given elsewhere [3].

The JMF asphalt content of 5.6% gave a VTM of 3.0% (the state agency accepts the VTM as low as 3.0%) and a VMA of 16.2%. The amount of material passing No. 200 (P200) sieve in the JMF was 5.1%. However, when the HMA production began, a VTM close to 1.7% and a VMA close to 14.5% was obtained at an asphalt content of 5.6% and a P200 content of 5.0%. The produced gradation was reasonably close to the JMF gradation. Therefore, the HMA producer reduced the JMF asphalt content from 5.6 to 5.2%. Thirteen sublots of HMA were produced with the reduced asphalt content of 5.2%. An average production VTM of 2.67% and VMA of 14.5% was obtained.

It was evident that the mix composition needed to be adjusted further to increase the VTM to 3.0% or higher. The asphalt content was further reduced from 5.2 to 5.0% for three consecutive sublots. However, there was no improvement in the VTM value obtained with a limited number of tests. The contractor reduced the asphalt content again from 5.0 to 4.7% for the last 35 sublots of the project. This final decrease in the asphalt content increased the average VTM to 2.91% (closer to the target of 3.0%). Therefore, the following changes occurred during the entire paving period:

Change in asphalt content from 5.6% to 4.7% = 0.9%
Resulting change in VTM from l.7% to 2.9% = 1.2%

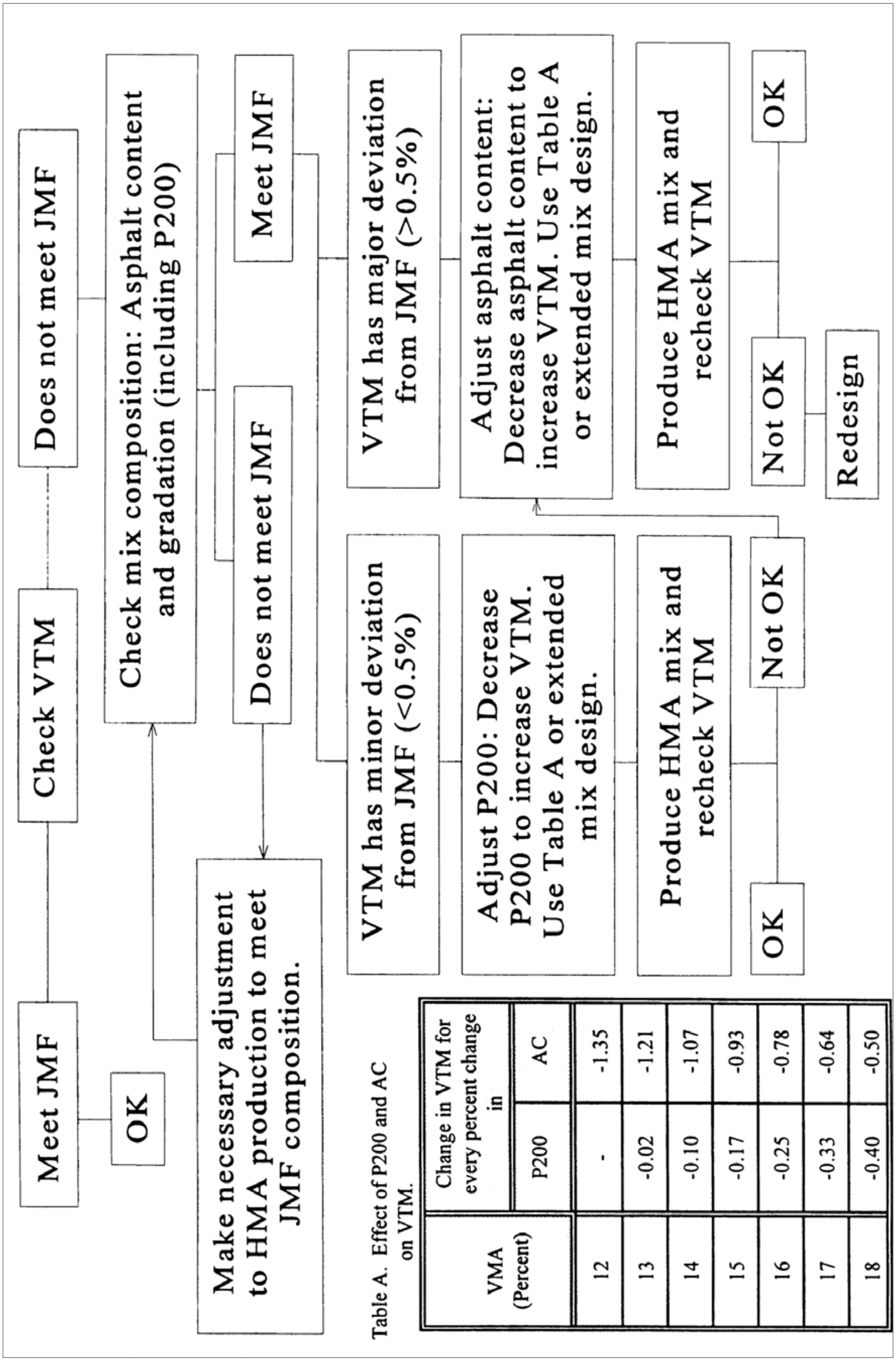

Table A. Effect of P200 and AC on VTM.

VMA (Percent)	Change in VTM for every percent change in	
	P200	AC
12	-	-1.35
13	-0.02	-1.21
14	-0.10	-1.07
15	-0.17	-0.93
16	-0.25	-0.78
17	-0.33	-0.64
18	-0.40	-0.50

Figure 2. Flow Chart for Reconciling VTM

This means that 0.9% reduction in asphalt content increased the VTM by 1.2%. This amounts to 1.2 ÷ 0.9 or 1.3% change in VTM by 1.0% change in asphalt content. The value of 1.3% compares reasonably well to the average value of about 1% corresponding to a VMA value of 14.5% in Table 6, based on all FHWA projects. In summary, this paving project had the problem of lower VTM in the produced mix compared to the laboratory designed mix. This was despite the fact that the produced mix was reasonably close in mix composition to the laboratory designed mix. This problem was resolved by lowering the asphalt content. The asphalt content could have been reduced drastically in one step if the proposed method of reconciliation was used, but the contractor chose to reduce it in three steps over the period of paving.

CONCLUSIONS AND RECOMMENDATION

The following conclusions can be drawn based on the statistical analysis of field data from 24 FHWA demonstration projects.

1. Significant differences existed between the volumetric properties of the laboratory designed and plant produced hot mix asphalt.
2. VMA is affected most by the amount of P200 material and the relative proportions of coarse and fine aggregates.
3. VMA can be increased by reducing the amount of P200 material or natural sand in the HMA mixes. VMA can also be increased by moving the aggregate gradation away from the maximum density line (MDL) especially for HMA mixes with no natural sand.
4. VTM is affected most by asphalt content, P200 material and the relative proportions of coarse and fine aggregates.
5. VTM can be increased by reducing asphalt content or P200 material or both.

The following recommendations are made to reconcile differences between the volumetric properties of the laboratory designed and plant produced hot mix asphalt.

1. Use the flow charts in Figures 1 and 2 as general guidelines for reconciling the VMA and VTM differences between the laboratory designed and plant produced HMA mixes.
2. Perform an extended mix design which will be useful in providing additional quantitative information for reconciling the differences in void properties that may arise during production. This information being mix specific is likely to be more reliable for making adjustment to the HMA mix. The recommended extended mix design consists of:
   a. Conventional mix design with a specific gradation used in JMF.
   b. Two additional levels of the material passing No. 8 sieve (JMF ± 5%).
   c. Two additional levels of P200 material (JMF ± 2%).
   d. Three levels of asphalt content (JMF ±0.5%).
   The extended mix design requires a total of 27 combinations (3 levels of No. 8 material × 3 levels of P200 × 3 asphalt contents) of which 9 will be taken care of already by the conventional mix design. If three briquettes are made for each combination, an additional 72 briquettes would be needed for the extended mix design (24 combinations × 3 replicates).
3. Attempt to reconcile the differences between the volumetric properties of laboratory designed and plant produce mixes during first day's production by testing at least 4 sublot samples and using the average test values.
4. After the differences in the volumetric properties are reconciled, maintain control charts for mix composition (asphalt content and gradation) and volumetric properties (VMA and VTM) during the entire production period.

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