used. The adoption of either of these provisions will result in fairer treatment of contractors and may eventually help to improve their generally negative attitude toward specifications of this type.

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Incentive and Disincentive Specification for Asphalt Concrete Density

C. S. HUGHES

ABSTRACT

The background for a specification that includes both positive and negative price adjustments for the density of asphalt concrete is presented. The results that have been obtained since the specification was introduced in 1978 are described. The incentive features of the specification are emphasized, because it is believed that they are unique and have been the primary reason that improved densities have been obtained in Virginia during the last 6 years.

Virginia has used the control strip procedure and nuclear gauges to measure compaction on construction projects since 1966 (1,p.309). However, in the 1970s, with the Interstate system nearing completion, more and more plant mix was being used for maintenance overlays let to contract, and, for several reasons, no one method was used consistently to check densities on this work. A question arose about the adequacy of the compaction being attained, and an examination of the densities obtained for maintenance projects in 1975 and 1976 showed that only 16 percent met the specification then on the books but not widely applied (2). Consequently, an analysis was made of the specification to determine its severity, and a more realistic specification that contained pay factors based on performance criteria was developed. The new specification was first used in 1977 as a special provision for information only. In 1978 and 1979 it was used as a special provision with half of the price adjustments applied, and for the last 4 years it has been used in its entirety.

PRE-1977 SPECIFICATION

Section 320.07 of the Virginia road and bridge specifications states in part:

> Rolling shall be continued until . . . a minimum density of 92% of the maximum theoretical density (MTD) has been obtained. Not more than 1 sample in every 5 shall have a density less than that specified, and the density of such sample shall not be more than 2% below the minimum specified.

This specification, assuming a normal distribution verified from data collected in Virginia, requires an average project density of at least 92.8 percent MTD when the standard deviation is no greater than 0.93 percent MTD, as shown in Figure 1. This requirement assures that on the average not more than one sample in every five shall be between 90.0 and 92.0 percent MTD. If the standard deviation is greater than 0.93 percent, an average project density higher than 92.8 percent is necessary to meet the specification.

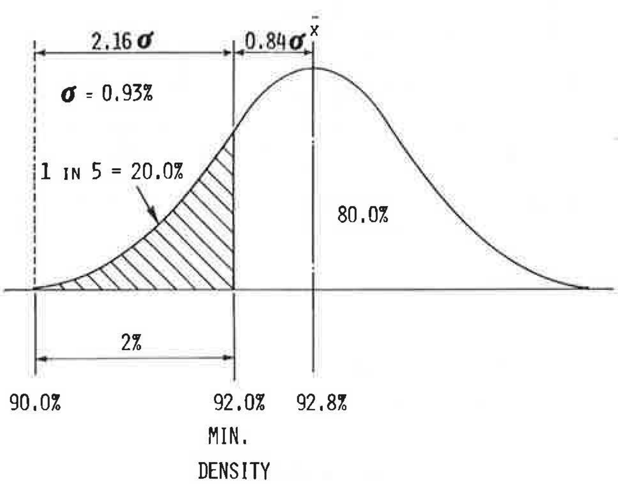

FIGURE 1 Virginia Department of Highways and Transportation pre-1977 density specification expressed statistically.

1976 DENSITY STUDY

The 1976 data indicated that the average density obtained statewide was 91.3 percent and that the standard deviation was slightly greater than 1.3 percent. Expressed in terms of a normal distribution, the density data are shown in Figure 2. Instead of 20.0 percent of the density values being lower than 92.0 percent, 70.0 percent were actually lower. On the other hand, two of the state's construction districts had average densities of 92.3 and 92.5 percent, which indicated that the average of 92.8 percent in the existing specification was not quite attainable, but almost so. However, the implied standard deviation of about 0.9 percent was too severe. Although they averaged 1.3 percent, the standard deviations from the 1976 study ranged only from 1.2 to 1.5 percent within each district.

One recommendation from the 1976 study was that a price adjustment system using the results of density

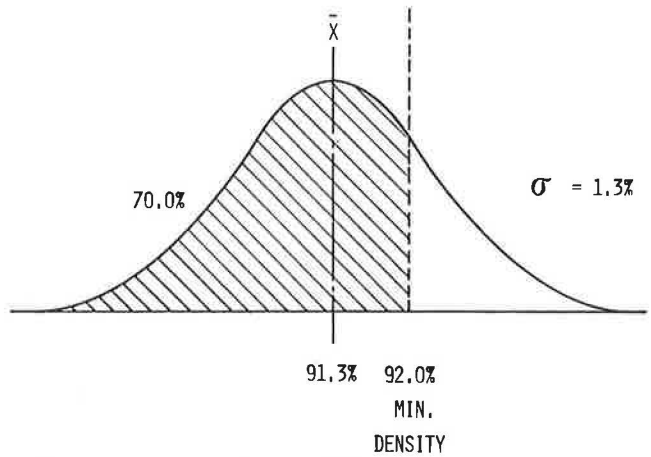

FIGURE 2 Statewide average of density in 1976 expressed in a normal distribution.

tests to determine conformance to specifications be instituted.

NEW SPECIFICATION WITH PAY FACTORS

Several assumptions were made in developing the new specification:

1. The 1976 data indicated that the control strip procedure was not ideal for use on maintenance overlays. This was especially true in the development of a specification with pay factors and meant that density cores must be used.
2. An average density of 92.5 percent MTD is achievable, as was demonstrated by the results in one district in 1976.
3. A standard deviation of 1.3 percent MTD, obtained on the statewide average in 1976, is reasonable.
4. The optimum construction density is in the range of 92.0 to 94.0 percent MTD. (This is based on the assumption that the density will increase approximately 2.0 percent under traffic.)
5. The analysis is based on the normal curve. As indicated previously, this assumption has been verified.
6. The overlay design life is 10 years.
7. A loss of 1.0 percent MTD reduces design life 1 year and is a linear function.

These assumptions produce a specification that defines acceptable product as shown in the form of a normal distribution in Figure 3.

In developing the pay factors, the primary assumption was that they should be consistent with

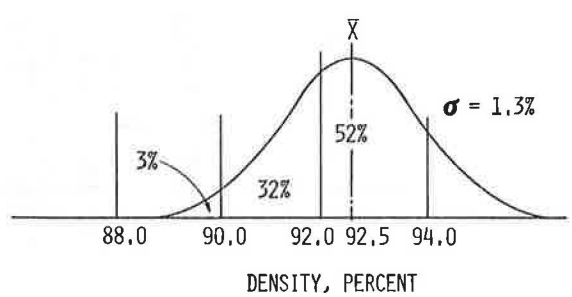

FIGURE 3 Acceptable product.

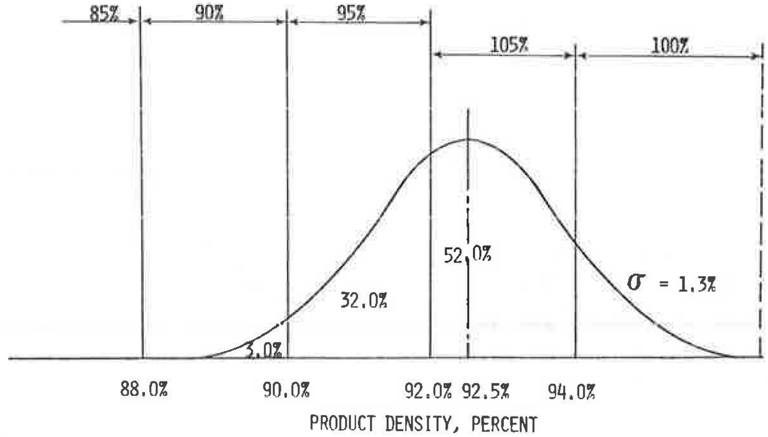

FIGURE 4 Price adjustment factors.

pavement life. The present worth concept was used for the price adjustments derived from the average values over the density interval considered. This specification also provided an ideal opportunity to try to use a bonus concept. On the basis of the fourth assumption, if more of the population than expected is in the range of 92.0 to 94.0 percent, the service life of the overlay is expected to be longer than the design life. Figure 4 shows the acceptable product with the pay factors. Only two conditions will allow the pay factor to be greater than 100.0 percent. One is for the average density to increase from 92.5 to 93.0 percent with a standard deviation of 1.3 percent or less. The other possibility for a bonus is for the variability to be lower than 1.3 percent and the average to remain in the 92.5 to 93.5 percent range.

The average density and standard deviation are calculated and used to estimate the distribution of the population. This may seem to be a complicated procedure, but the calculations are computerized and provide a printout as shown in Figure 5.

Items specially pertaining to the statistical application of the specification are

- Random sampling--A necessity in any statistically oriented specification.
- Lot size--A contract item, which may be a grouping of similar sections of roadway in maintenance overlays or a particular mix type in a construction project.
- Sample size--Samples are taken at the minimum rate of one per 0.5 mile per lane; however, the minimum sample size is seven. For 148 contract items in 1983, the average sample size was 24, with 28 items having 10 or fewer samples and 20

PLANT ADAMS CONSTRUCTION CO
BURKEVILLE VA

SCHEDULE NUMBER 30383 PAY FACTOR COMPUTATION

CONTRACT ITEM NUMBER 3-E -3				INTERVAL	%	NET %	P. F.	% PAY
MIX TYPE I-2				0-88	0.0	0.0	.85	0.0
SUMMARY STATISTICS:	AVG.	ST. DEV.	N	88-90	0.0	0.0	.90	0.0
CONTRACT ITEM-MIX	93.2	0.8	18	90-92	5.9	0.0	.95	0.0
ROUTE 0360	93.2	0.8	18	92-94	77.0	25.0	1.05	26.250
				94-100	17.1	17.1	1.00	17.100
						57.9	1.00	57.900
				TOTAL PAY FACTOR				101.250

TEST RESULTS

TEST NUMBER	% DENSITY	DEPTH	ROUTE	APPLICATION RATE	DATE TESTED	EDIT
1	93.4	1.63	0360	150	830825	
2	94.0	1.75	0360	150	830825	
3	94.5	2.00	0360	150	830825	
4	94.1	1.88	0360	150	830826	
5	91.5	1.75	0360	150	830826	
6	93.1	1.75	0360	150	830826	
7	93.6	1.63	0360	150	830829	
8	94.0	2.00	0360	150	830829	
9	94.2	1.75	0360	150	830829	
10	93.4	1.75	0360	150	830830	
11	92.3	1.75	0360	150	830830	
12	93.4	1.63	0360	150	830830	
13	93.0	1.50	0360	150	830831	
14	92.4	1.50	0360	150	830831	
15	92.4	1.50	0360	150	830831	
16	92.4	1.63	0360	150	830901	
17	93.5	1.50	0360	150	830901	
18	93.2	1.63	0360	150	830901	

FIGURE 5 Printout of density data.

items having more than 40 samples. [Theoretically a "t" distribution rather than a normal distribution should be used for small samples (i.e., for n < 25). This refinement is not used in this specification.]
- Risks--The seller's risk, α, is 0 percent. The department's risk, β, is shown in the operating characteristics curve in Figure 6.

A copy of the special provision is appended.

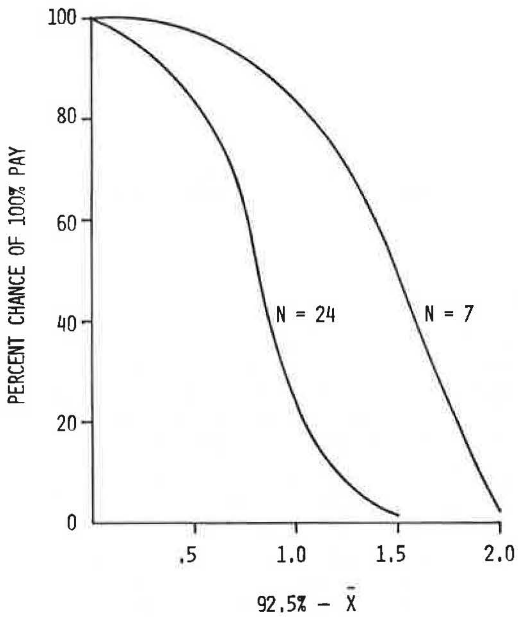

FIGURE 6 Operating characteristics curve (assuming $\sigma = 1.3\%$ and 100% pay).

FIELD TESTS

Samples are taken as soon as practicable after rolling by cooling the pavement with CO_2 or dry ice and sawing two adjacent 4 in. x 4 in. dry plugs. The two plugs (two are taken to minimize the within-test error) are carefully removed from the pavement, weighed in air and water on the project by the state inspector, and compared to the MTD value. Obtaining an accurate MTD value has occasionally been a problem. It is suggested that on the first day of paving a calculated MTD value using the percentages and specific gravities of each ingredient be used. After that, at least one Rice MTD (ASTM D2041-78) is determined daily from the mix, and a running average of the Rice MTD is used as the project progresses.

RESULTS

The specification was developed in an effort to improve pavement performance through increased densities. Although no direct indications of improved performance have yet been noted, the improved densities achieved through this specification are readily apparent (Table 1).

The improvement in density has been steady and, contrary to earlier belief, it has been achieved primarily through improved mix design, not increased rolling. The improvements have consisted of additional attention to mix design and additional emphasis on choosing the asphalt content on the basis of the voids total mix. Further improvements are possible for some mixes; however, it is fair to state that personnel of both the department and contractors are more aware of density results than ever before. The 1983 pay factors are shown in Figure 7.

TABLE 1 Density and Pay Factors by Year

	Year						
	1976	1978	1979	1980	1981	1982	1983
Average density (%)	91.3	91.6	92.0	92.6	92.7	93.1	93.1
Standard deviation (%)	1.3	1.6	1.5	1.3	1.2	1.2	1.1
Pay factor (%)		97.3	97.9	98.9	99.7	100.4	100.4

PROBLEMS

The implementation of the new specification has not been without problems. Contractors have complained that it has been applied on roads with weak bases and that the level of compaction required cannot be obtained. Another complaint is that some roads are so badly out of section that the thickness of the overlay varies and the densities vary with it.

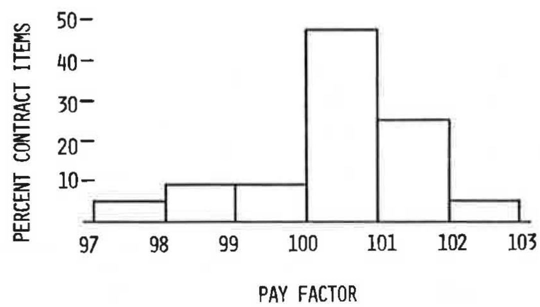

FIGURE 7 Distribution of pay factor for 1983.

Although both complaints have validity, results have shown no difference in densities obtained on secondary roads as opposed to those on primary and Interstate pavements. This would indicate that overlays on the secondary roads with typically weaker bases can be as adequately compacted as those on primary and Interstate pavements. As for the variation in thickness, the standard deviation of 1.3 percent was obtained on roads that represent typical variations in thickness.

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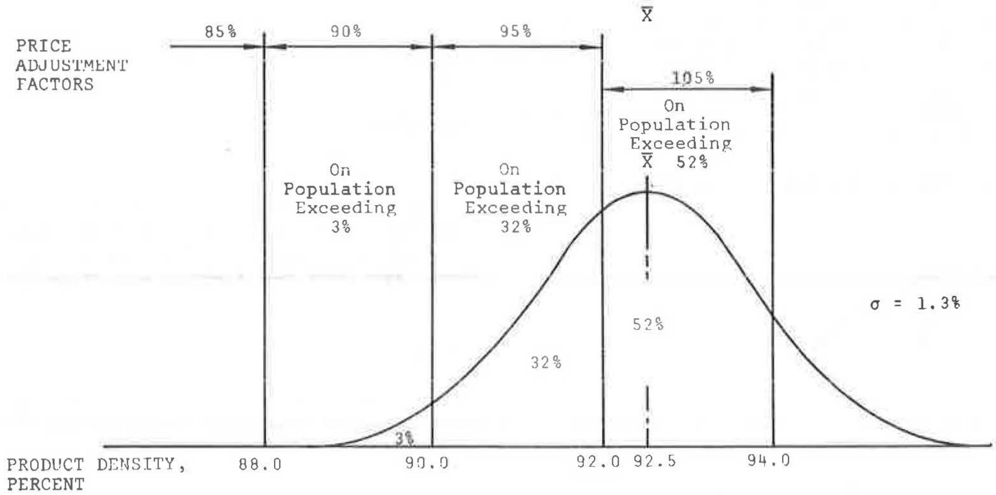
APPENDIX: VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION SPECIAL PROVISION FOR SECTION 320

May 24, 1983

The requirements of this provision will apply to only Bituminous Concrete, Types S-4 and S-5 applied

TABLE 1



at a rate of 125 psy or greater and Type I-2 applied at a rate of 150 psy or greater.

Section 320.04 Equipment of the Specifications is amended to include the following:

(c) Rotary saw--a gasoline powered rotary saw with carbide blades shall be furnished for cutting test samples from the pavement. The Contractor shall also furnish all gasoline, oil, additional carbide blades and maintenance for the rotary saw as well as a means to cool the pavement sufficiently to saw samples from the road prior to its becoming unworkable.

Section 320.07 Compaction of the Specifications is amended to replace the sixth, seventh and eighth paragraphs with the following:

Rollers shall move at a slow but uniform speed with the drive roll or wheels nearest the paver. Rolling shall continue until all roller marks are eliminated and the required density is obtained.

Sampling for density determination on the main line will be at the rate of no less than one per mile per lane for contract items in excess of 50,000 tons and no less than one per 0.5 mile per lane for contract items of 50,000 tons or less; however, no less than seven samples will be obtained from the lot regardless of the size of the contract item. Crossovers and connections will not be sampled for density; however, the tonnage contained therein will be included in the lot. The lot size will be the quantity of bituminous concrete furnished by each plant for the contract item. Tests will be performed in accordance with VTM-6.

The population of the densities obtained from the lot will be calculated using standard statistical procedures and will be compared with the Standard Normal Distribution shown in Table 1 which describes the population of densities for material having an average density of 92.5% of theoretical maximum and a standard deviation of 1.3%.

The Contractor shall advise the Department when rolling operations are complete to the extent that samples can be secured and shall assist in cutting and securing such samples. In the event three consecutive density tests are below 91% of theoretical maximum density, the Department reserves the right to require the Contractor to discontinue bituminous concrete operations until appropriate corrective action is taken to ensure densities in excess of 91% of theoretical.

Section 320.12 Basis of Payment of the Specifications is amended as follows:

The first sentence of the first paragraph is completely replaced by the following:

Except as otherwise specified herein, the accepted quantities of bituminous concrete will be paid for at the contract unit price per ton for the type of bituminous concrete specified.

The following paragraphs are added:

Payment for the quantity of material calculated as being under the standard normal distribution curve and that calculated as having a density equal to or greater than 94% of theoretical maximum density will be at the contract unit price per ton for the type bituminous concrete specified. Price adjustment factors as shown in Table 1 will be applied to the quantity of material calculated as having a density less than 94% of theoretical maximum density and being outside the standard normal distribution curve in accordance with the following:

% of Theoretical Maximum Density	Quantity in Excess of (%)	Price Adjustment Factor (%)
Less than 88	0	85
88 to 90	3	90
90 to 92	32	95
92 to 94	52	105

The cost of furnishing equipment, supplies and assistance for obtaining the samples shall be included in the price bid for the material.

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