Roadway Sampling Evaluation

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ABSTRACT

The Florida Department of Transportation (FDOT) has traditionally required that all sampling and testing of asphalt mixtures be at the Contractor's production facility. With recent staffing cuts, as well as budget reductions, FDOT has been considering alternative sampling methods which will provide greater staffing flexibility, while at the same time provide assurance that a quality product is placed on the roadway. One of the methods being considered is sampling the asphalt mixture at the roadway.

The first objective of this study was to conduct a literature review and survey which included interviewing various transportation engineers to determine which agencies require, or allow, field sampling for acceptance and whether those efforts have been successful. The second objective of this study was to evaluate the sampling and testing variability of samples taken at the plant compared to those taken from the roadway mat and from the paver auger. A statistical evaluation was performed to compare results from this study to the specification limits currently being used. Superpave 9.5 mm and 12.5 mm mixes were sampled on 11 dense-graded projects, and two FC-5 projects (Open-Graded mix) were sampled and tested.

The survey showed as many agencies require sampling from the roadway as require sampling from the plant; but when agencies allow either location, samples are most often taken from a loaded truck at the plant. When roadway samples are taken, most often those samples are taken from the mat behind the paver.

For dense-graded mixes, individual test tolerances for air voids, and Gmm and Gmb values of limestone mixes will need to be increased if roadway samples are to be used for acceptance or comparison with contractor results. The differences for percent passing the No. 200 sieve were statistically significant for auger samples, but deviations were within current tolerances. Asphalt content was significantly affected by roadway mat samples, but deviations were within current tolerances. Roadway samples of FC-5 mix from both the mat and auger were statistically different than the contractor and FDOT samples taken at the plant. Roadway sampling is not recommended for FC-5 mixes.

Keywords: Sampling, Percent within Limits, specification limits

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PART 1 - ASPHALT MIXTURE SAMPLING SURVEY

INTRODUCTION

The Florida Department of Transportation (FDOT) has traditionally required that all sampling and testing of asphalt mixtures be at the Contractor's production facility. With recent staffing cuts, as well as budget reductions, FDOT has been looking at alternative sampling methods which will provide greater staffing flexibility, while at the same time provide assurance that a quality product is placed on the roadway. One of the methods being considered is sampling the asphalt mixture at the roadway.

Previous studies conducted by FDOT have shown greater variability in some instances when the material was sampled at the roadway. One possible source of this variability was the samples were taken from the paver auger in an effort to minimize the potential impact on pavement smoothness that would result from sampling behind the paver. Another possible source of variability is Florida's absorptive limestone materials. The additional handling time associated with sampling at the roadway and the ensuing transportation of the sampled material back to the asphalt plant for testing may result in additional binder absorption into the aggregate and a corresponding change in measured mixture properties.

The first objective of this study was to conduct a literature review and survey which included interviewing various transportation engineers to determine which agencies require, or allow, field sampling for acceptance and whether those efforts have been successful. A description of various procedures used is described in this report and will be evaluated to determine the best location to sample from the roadway. A summary of that survey is included in Appendix A.

SAMPLING LOCATION

A nationwide survey of the 50 states (plus the District of Columbia and Commonwealth of Puerto Rico) indicates there are as many agencies requiring sampling from the roadway as from the plant. The survey showed 22 agencies sample from a truck at the plant, 22 agencies sample from the roadway, and 8 agencies allow both plant and roadway sampling (Figure 1).

Of the eight agencies allowing sampling at either location, only two states (Hawaii and Montana) sample routinely from the roadway. The other six agencies typically sample from the plant. One of those states, Minnesota, has recently changed from requiring only roadway samples to allowing truck sampling as well in order to obtain timely test results. Based on the eight states that allow sampling at either location, plant sampling is the preferred method when either sampling location is allowed (Fig. 2). Contractors prefer plant sampling because it significantly reduces the lag time between when the mix is produced and when test results are known, eliminates the logistical problem of getting samples from the roadway back to a laboratory for testing, is often perceived to be safer, and eliminates potential smoothness issues if samples are taken from the mat.

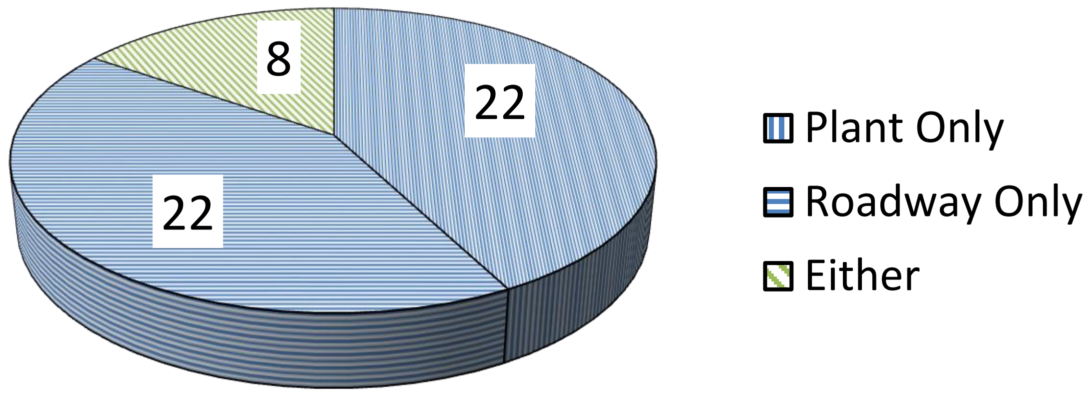

FIGURE 1: Agency Specified Location for Sampling Asphalt Mixture (52 Agencies).

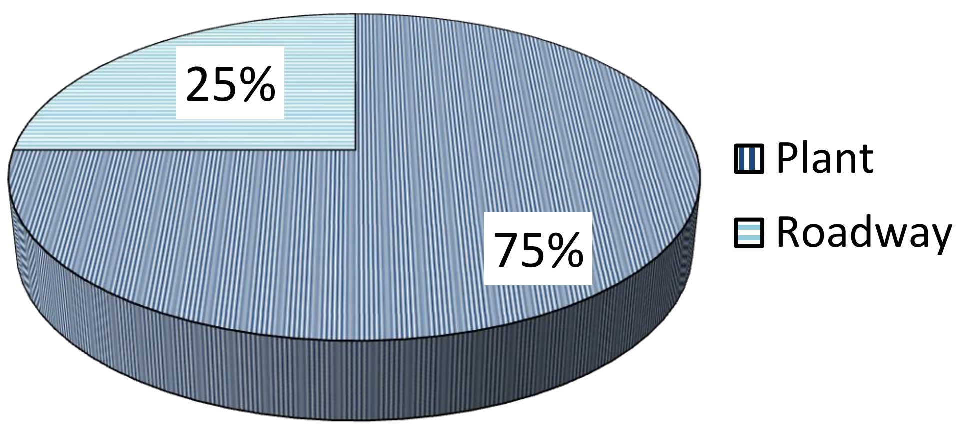

FIGURE 2: Sampling Location When Either Plant or Roadway Sampling is Allowed (8 States).

From Figure 3 it is evident plant sampling is most prevalent throughout the south and eastern portion of the country. In the midwest and western states, roadway sampling is more widely used. This may be because plants are more widely scattered in less populated areas, and windrow operations are more widely used.

Safety

The reasons for sampling at either location were sometimes in contrast with one another. For example, safety was often mentioned as a reason for sampling from the roadway. Agencies are reluctant to have technicians climbing onto, into, or around trucks loaded with hot asphalt mixture due to safety concerns that a technician may get burned.

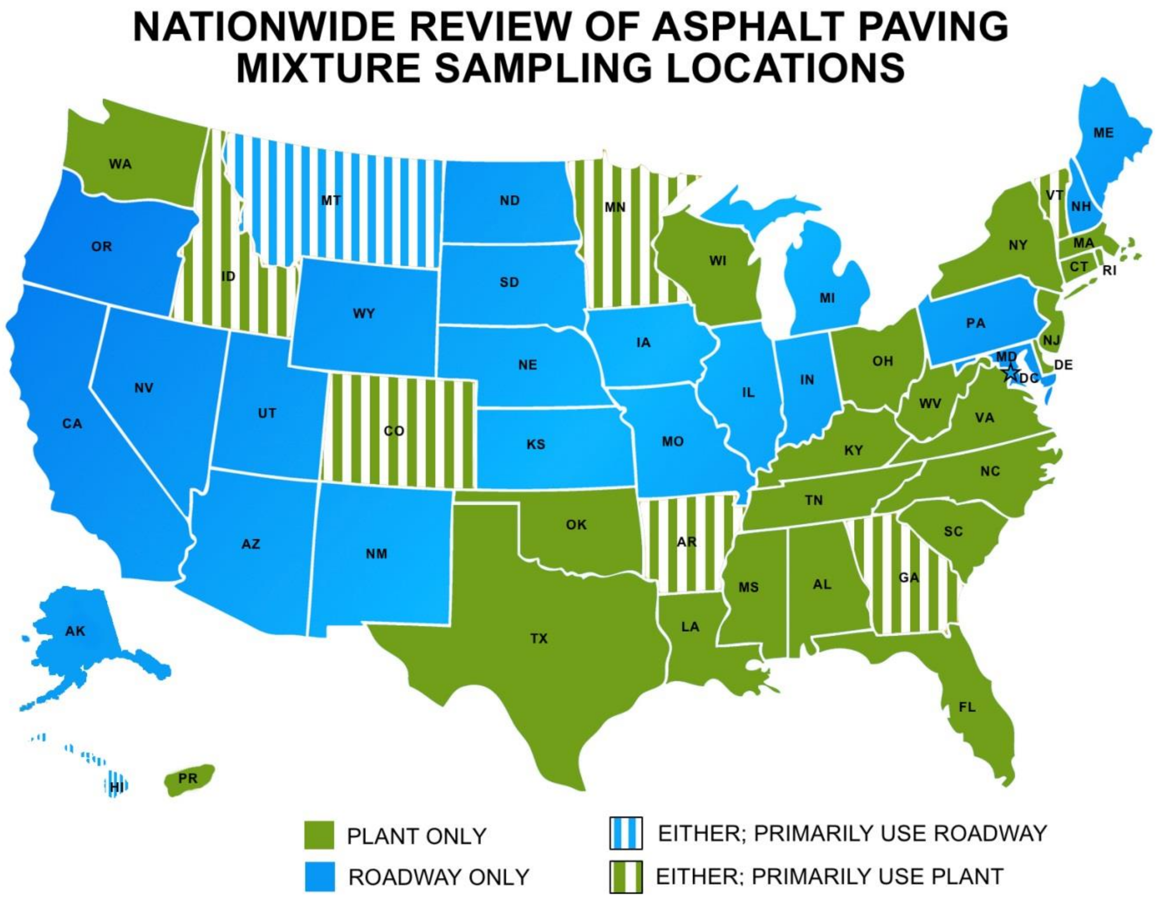

FIGURE 3: Nationwide Review of Sampling Location.

However, other agencies also quoted safety concerns as a reason for sampling at the plant. Those agencies expressed concern with having technicians stopping the paving operation, and walking on hot asphalt material next to live traffic while obtaining roadway samples. One agency that had previously sampled only from the roadway stated they switched to sampling at the plant just to address the safety concern of technicians working next to live traffic. However, with a little care, taking samples from a sampling platform at the plant or from the roadway can be done without jeopardizing safety. For example, auger samples could be taken from the side of the paver away from traffic (and it would not cause smoothness to be affected because paver stops and mat repairs would not be needed).

Roughness

At least 10 agencies mentioned concerns/complaints initially from contractors that the practice would result in increased roughness due to having to patch several areas across the mat. For thin lift overlays, the size of the sample site may be somewhat large in order to get a sufficient quantity of material for all the testing needed. For that reason, California allows plant sampling when the mixture is placed in thin layers. Some agencies stated complaints eventually went away, but at least four states indicate it is still an issue.

A couple of agencies have agreed to eliminate the sample sites from smoothness calculations if it affects the ride quality. They also add that, in reality, it has not been an issue. At least 15 agencies reported roadway sampling did not affect smoothness requirements.

Joint Contract Effort

One agency pointed out a potential problem with roadway sampling on contracts involving joint effort with another contractor. In New York it is more customary to have one contractor produce the mixture and another contractor place the mix. In those situations, it would be difficult to decide which contractor is responsible if repairs, replacement, or reduced pay factors are assessed. For example, low in-place density may be caused by roadway factors such as inadequate rolling effort, frequent paver stops allowing the mix to cool, or segregation of the mix through the paver. Low density may also be caused by plant factors such as changes in material proportions, gradation, asphalt content, or mix temperature. The real cause for low density may be a combination of several of these factors involving both plant and roadway variability so that neither plant nor roadway can totally be responsible for the problem.

Comparison of Sampling Location

Agencies allowing sampling at either plant or roadway, as well as those that have switched from one location to the other, use the same tolerances for mixture control and acceptance regardless of sample location. Minnesota reported having done a limited in-house evaluation, but there were no significant differences based on sample location. New Hampshire reported the limited informal comparisons they made before switching to roadway sampling seemed to show that roadway samples were about two percent coarser than plant samples. No formal report was available for the studies in either Minnesota or New Hampshire.

Only Indiana had conducted a formal study comparing results of plant versus roadway sampling during their transition from plant sampling to requiring roadway samples. The study was conducted by Ronald Walker, Bituminous Engineer and Michael Prather, Assistant Bituminous Engineer from 1992-1993 (*Walker, 1992; Walker, 1993; Prather, 1994*).

A comparison in 1992 of samples from the plant versus roadway samples taken from a variety of projects with different paving equipment, etc. showed results compared very favorably except in two areas. The asphalt content of roadway samples was consistently lower than plant samples while the percent passing the No. 200 (0.075 mm) sieve was about one percent higher. It was found that the total percent asphalt from the roadway was very nearly the same as the effective asphalt content in the mix design. This indicated that additional absorption was taking place that was not being accounted for in the standard one hour curing time at compaction temperature during the mix design procedure. As a result, the curing time was increased to four hours at the compaction temperature. The four hour aging resulted in a maximum loss of 0.4% asphalt which corresponded to the asphalt content obtained from roadway samples. Since asphalt content is based on total binder, this difference in results indicates technicians were not able to completely remove all of the absorbed binder during the extraction process.

Indiana also found that for surface mixes, the percent passing the No. 200 sieve was about 1.0 % higher than the plant samples. When the study was continued in 1993, the percent tolerance allowed on the No. 200 sieve was increased by 1.0 percent. It was further found that mixes with local sand did not vary from the plant samples as much as crushed quarry stone. It was also uncertain whether the differences were from the total effect of handling which includes: hauling, dumping, transfering through a materials transfer device and/or the paving machine, augering, breaking down of materials under the vibrating paver screed or from segregating particles transversely across the mat. To evaluate the possibility of transverse segregation, 18 samples were taken for comparison at different locations across the mat. One foot from the edge on each side of the mat was excluded leaving 10 feet of sample width that was divided so that three feet from the wheelpath area on each side was compared to samples from the four foot section in the middle of the mat. Results given in Table 1 show no significant differences.

TABLE 1: Results of Transverse Roadway Sampling (Indiana)

	Transverse Location				
	1’	3’	4’	3’	1’
Sieve	Average Percent Passing				
No. 4		62.7	63.0	62.3	
No. 30		24.0	24.2	24.1	
No. 200		2.9	3.0	2.7	
No. of Tests		7	5	6	

An evaluation of 1993 data showed that four hour aging at the compaction temperature was very effective at accounting for all the binder absorbed into the aggregate. The pooled data from 1992 and 1993 was evaluated and found to be within the testing tolerances whether samples were obtained from the plant or roadway. The standard deviation of samples from the two-year study was less than the standard deviations used in establishing the original specification tolerance values. Thus it was concluded that either plant or roadway sampling could be used with equal confidence that results would meet specification ranges for variability. It was also shown that the additional 1.0 percent tolerance on the No. 200 sieve for surface mixes was not necessary.

The data from the study also showed the benefit of using a Materials Transfer Vehicle (MTV). Test variability was reduced in some cases about 50% when a MTV was used compared to pooled results from similar projects where a MTV was not used (Figure 4).

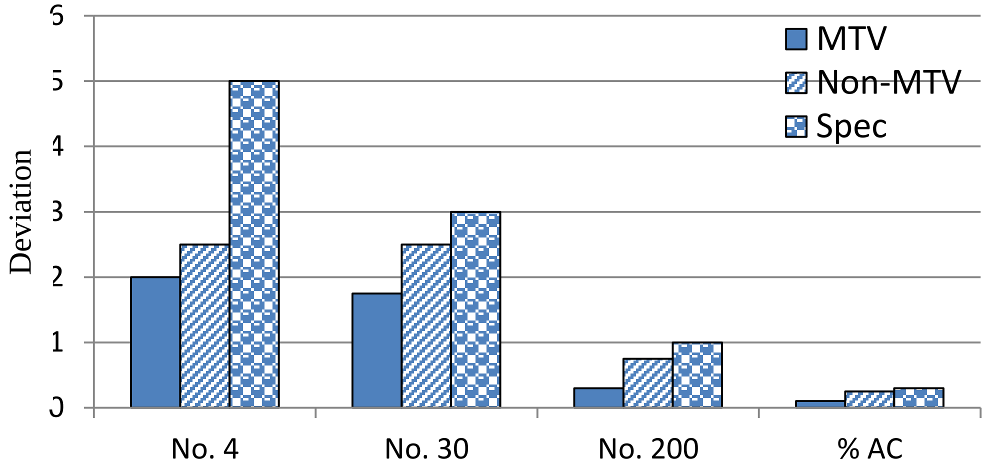

FIGURE 4: Comparison of Deviation in Test Results With and Without MTV.

Since the 1993 report, Indiana has implemented use of Superpave mixtures and no longer bases acceptance on gradation. Mixture is now accepted on the basis of VMA and air voids at N_{design} and asphalt content.

Location of Roadway Sampling

By far, roadway samples are most often taken behind the paver (Figure 5). That is the last point in the process considered feasible for taking samples of asphalt mixture. Samples that are most representative of the final product would need to be taken after compaction to account for aggregate breakdown during the compaction process. However, this would require a multitude of roadway cores and makes such sampling impractical. Therefore, sampling behind the paver is thought to provide samples most representative of the finished product.

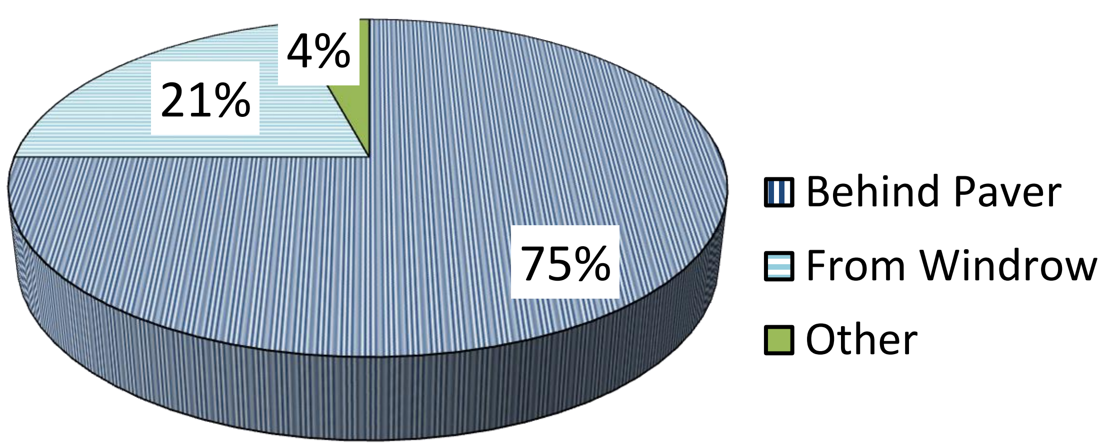

FIGURE 5: Location of Roadway Samples.

A couple of agencies avoid sampling from behind the paver due to concerns it may affect roadway smoothness. When those agencies do not permit windrow construction, they sample from the paver hopper or auger chamber. However, one agency reported taking samples from the MTV.

Sampling from the MTV seems to be the safest place to sample. In this case, the MTV is advanced well ahead of the paver, the discharge conveyor is swung over to the shoulder, and mixture is discharged directly into sample cans for transport. There are several obvious benefits from sampling from the MTV.

- Safety is improved because technicians can take samples on the shoulder of the roadway well out of danger from live vehicle traffic.
- The paving operation does not have to be stopped while samples are taken or repairs are made.
- Roadway smoothness is not affected. (However, the literature suggests smoothness was not affected by any form of roadway sampling.)
- Remixing through the MTV is accounted for.
- Certain mix types, such as leveling, do not need to be excluded.

Instead of transferring mix directly into sample cans, Illinois has some specially designed sampling devices mounted into the bed of a pickup or pull-behind trailer. The device, pictured in Figure 6, has a trapezoidal shaped funnel mounted directly above a sample splitter so split samples are obtained at the roadway. One set of samples goes to the contractor's plant laboratory, and a comparison set goes to the DOT laboratory.

FIGURE 6: Sample Splitter for Taking Samples from a MTV (Illinois).

LIMITATIONS OF ROADWAY SAMPLING

For agencies typically sampling from the roadway, exceptions where samples are taken from the truck at the plant are generally based on mix type or layer thickness. Exceptions reported by several agencies were:

- Open Graded Friction Course (OGFC)
- Mix for leveling courses
- Mix for thin lifts (thickness < 2 x NMAS)
- Mix for low volume projects/small quantities

Required sample size plays a major part in determining where to take samples. This decision is based on the fact that some agencies require 100 lb. samples, or more, in order to have sufficient material to determine G_{mb}, G_{mm}, extraction, tensile strength, etc. And generally, material for three or four comparisons (contractor, DOT, referee sample, and Independent Assurance) is needed. Samples with this much mass would require disrupting a large area of the mat, especially when thin layers are being placed. For example, if three 100 lb. samples were taken, it would require an area approximately 3’ x 6’ in order to provide sufficient material if the mat was being placed at 1.5 inches thick.

The Indiana study also found roadway sampling using metal plates was limited to certain types of equipment. When windrows were used, the plates would interfere with the windrow pickup device. In order to resolve the problem, the paver and windrow pickup machine had to be stopped and the plate placed between the two machines. However, this presents safety concerns in having technicians go between two pieces of roadway equipment to place the plates, as well as smoothness concerns from having to stop the paver.

An alternative to mat sampling is using auger samples. The samples could be taken away from the side of live traffic, and the paver would not have to stop. Smoothness would not be affected as well because mat repairs would not be needed.

Mix placed on shoulders or in widening trenches also does not lend itself very easily to typical roadway samples. When placing shoulder widening in narrow trenches, one agency requires that a small amount of material be dumped on the roadway and sampled like a stockpile sample.

It may be difficult to decide whether to adjust plant production based on roadway samples. For example, if the samples are taken in a segregated area caused by the paver or placement operation, then the problem is a segregation problem and not a mix problem. In this case, adjustments should not be made to plant production based on testing of in-place mixture.

REASONS FOR ROADWAY SAMPLING

The reason most often given for roadway sampling was agencies believed sampling at the last point possible in the production and placement process would provide samples most representative of the in-place materials. Some agencies also believed sampling behind the paver was more statistically appropriate in order to obtain samples more representative of the final product. Others commented that they were encouraged by their local Federal Highway Administration (FHWA) to incorporate roadway sampling along with the “Percent Within Limits” statistical quality control/acceptance program. For these reasons, many believe sampling behind the paver is the best place for roadway sampling (Figure 4). Seventy Five percent of those who sample from the roadway, typically sample from behind the paver. Those who sample from a windrow, paver hopper, auger chamber, or other roadway location do so mainly to prevent the possibility of causing roughness in the finished mat as a result of stopping the paving equipment, removing material, leaving footprints in adjacent areas, and patching the sampled areas.

A couple of agencies reported they believed it was more economical to sample from the roadway because it eliminated having to have a technician at the plant. However, more agencies believed it actually cost more to sample from the roadway due to logistical problems in getting samples to a laboratory for testing and for the increased risk to the contractor from delays in getting sample results.

HOW ROADWAY SAMPLES ARE TAKEN

As stated above, sampling from the MTV appears to be the safest, easiest, and least disruptive of the roadway sampling methods. However, not all agencies require use of a MTV, and those that do may not require them on projects that are not on the national highway system. When sampling from behind the paver, the number of agencies which use metal plates or templates is about equal to the number of agencies that do not require metal plates (Figure 7). A few agencies reported they initially used metal plates, but found them to be more trouble than useful.

Metal plates are subject to sliding on the pavement under the paver screed as mix is being placed. To avoid this, agencies nail down the plates. In order to find the plate after it is covered, many agencies require a thin wire be tied to the plate and extended out onto the shoulder or adjacent lane. After the mixture is placed, the wire is pulled up through the mat to locate the plate.

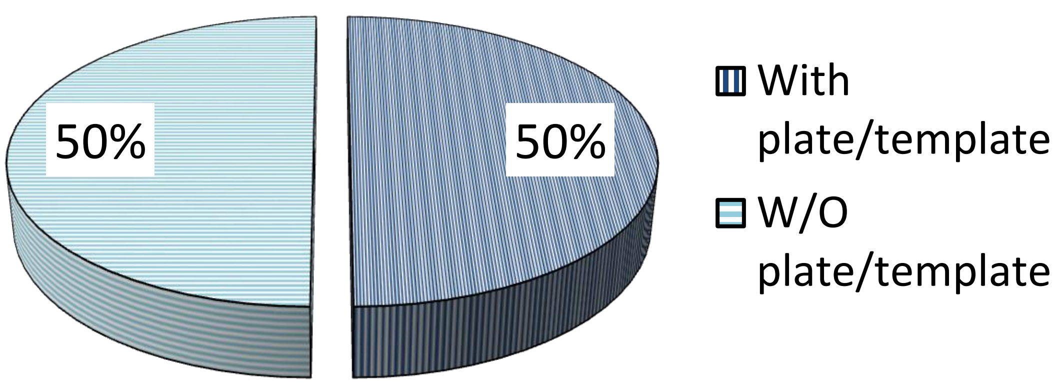

FIGURE 7: Use of Template or Plate for Roadway Sampling.

Some agencies use different size plates depending on the thickness of the layer being placed. It is easy to imagine that the weight of metal plates needed to obtain large sample sizes would be prohibitive. For that reason, several plates are used if more than one sample is needed to meet the minimum sample size requirements.

Most agencies take roadway samples transversely across the mat. But due to concerns the patched areas may affect smoothness, Illinois and Michigan (*Illinois, 2012*) require the samples be staggered in the longitudinal direction so that a pronounced bump from the patched areas is avoided (Figure 8).

Iowa requires a similar staggering of sample locations (*Iowa, 2009*) except the longitudinal distance is required to be spread over the distance of 30 tons of mixture (Figure 9). This is done to ensure sampling will span at least one exchange of trucks so any end-of-load segregation may be detected and accounted for. If additional sample mass is needed, samples are also taken at quarter points across the mat.

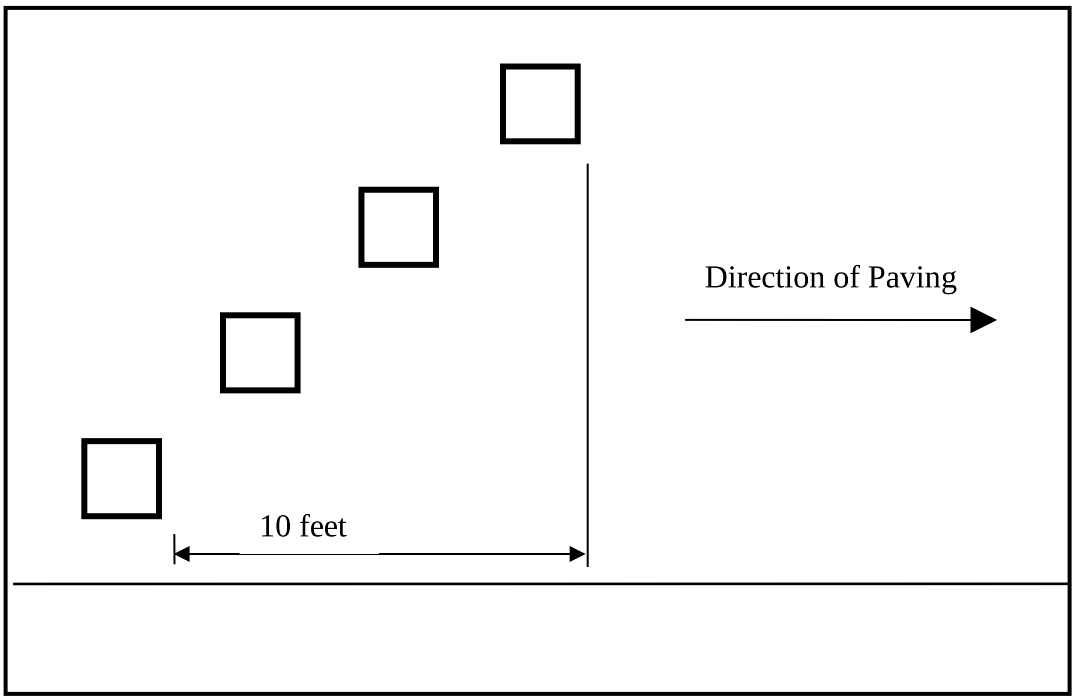

FIGURE 8: Sampling Layout When Sampling Behind the Paver (Illinois).

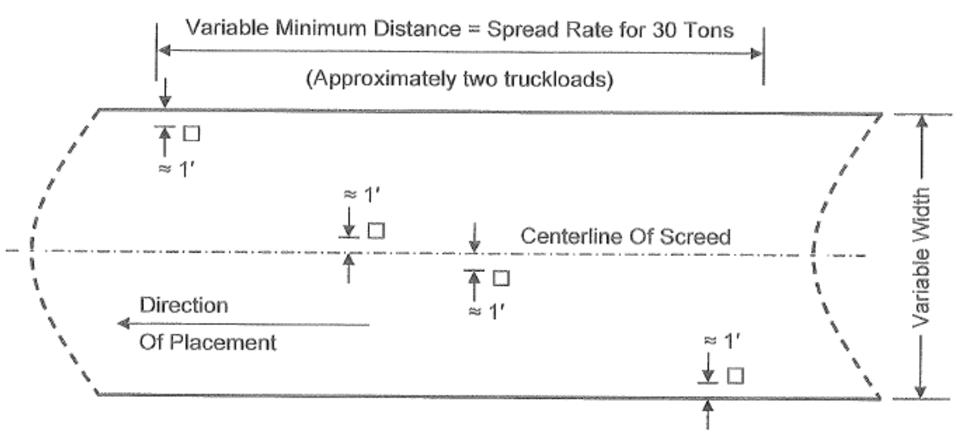

FIGURE 9: Staggered Sample Location to Extend for a Distance to Capture One Exchange of Trucks (Iowa).

PART 2 - EVALUATION OF FIELD SAMPLE RESULTS

FIELD SAMPLING

Florida Department of Transportation (FDOT) implemented the use of a statistically based percent within limits (PWL) specification for asphalt mixture acceptance in 2002 after a year of evaluating test data and making comparisons to the previous specifications used. The development of specification limits for a PWL procedure is described in NCHRP Report 447 (Russell, et al, 2001), and guidelines for pay factor determinations are provided in AASHTO Quality Assurance Guide Specification (AASHTO, 1996). Material property tolerances were adjusted based on engineering judgment so the average Lot pay factor was 1.0 with the goal of having the same pay for equal quality as with the specifications prior to 2002. FDOT followed up on the PWL implementation with another research evaluation in 2004 (Sholar, et al, 2005) (Sholar, et al, 2006). That evaluation was to assess how well the PWL specification was working in comparison to the specification prior to PWL, and to determine if additional fine-tuning of the 2002 values was needed. Three changes were made at that time: (1) the lower specification limit for roadway density of fine graded mixtures was increased, (2) a separate provision was made for situations where static rolling was required, and (3) plant lab air voids for fine and coarse graded mixtures were separated. Since then, another change has been made in that only fine-graded mixtures are produced.

The quality of asphalt mixtures for FDOT, except for roadway density, has been largely determined from samples taken from a loaded truck at the plant. One objective of this research was to compare the difference in sampling location on various projects throughout Florida and to determine if the variability from sampling location would make a significant difference in acceptance tolerances currently being used.

Samples were initially to be taken from 30 projects - three each from the eight Florida Department of Transportation (FDOT) construction divisions plus 6 open-graded friction course (FDOT FC-5 designation) projects. However, when replicates for each of 4 sub-lots were included, the testing amounted to a total of 480 extractions (30 projects x 4 sub-lots x 4 sample locations) 360 of which were to be run by FDOT personnel. The same technician was to run all the samples from three locations (from a truck at the plant, from the mat behind the paver, and from the paver auger) on each project to eliminate the testing technician as a possible factor for testing variability, but it was decided this would place a heavy workload on some technicians within each construction division. As a result, the research was scaled back to include 16 projects. However, some of the projects were delayed and therefore were not able to be sampled and included in the analysis. The result was only 13 of the proposed 30 projects were sampled: 5 projects used 9.5 mm mix, 6 projects used 12.5 mm mix, and 2 projects used FC-5 mix. No 19 mm mix samples were taken; however, 19 mm mix represents a small proportion (<1%) of the total mix placed in Florida.

FDOT technicians sampled from a loaded truck at the plant at the same time the contractor's technician took a sample. A portion of the cone of material was shoveled away and samples were taken from the interior of the cone as shown in Figure 10. The truck was then followed to the roadway so roadway samples could be taken from the same load of material as the truck samples were taken. Three roadway samples were taken at random transversely across the mat behind the paver as shown in Figure 11.

FIGURE 10: Truck Sampling Procedure

A single shovel full of mix was taken at each location and combined. Sampling within one foot of the longitudinal edge was avoided. The sampled areas were then filled with mix and raked smooth as in Figure 12. In addition, a sample was also taken from the auger chamber of the paver. For safety reasons, the auger samples were taken on the side away from traffic. On some projects the end gate of the paver was so close to the paver tractor tires that it was difficult to get a shovel into such tight quarters (Figure 13).

Once sampling was completed, the samples were taken back to the contractor's plant laboratory for testing. All roadway samples taken by FDOT were run by the same technician who ran the FDOT plant samples so that both technician variability and laboratory variability were eliminated as factors that might affect the test analysis. The test results were then evaluated for statistical analysis of sampling location variability.

FIGURE 11: Sampling Transversely Across the Mat

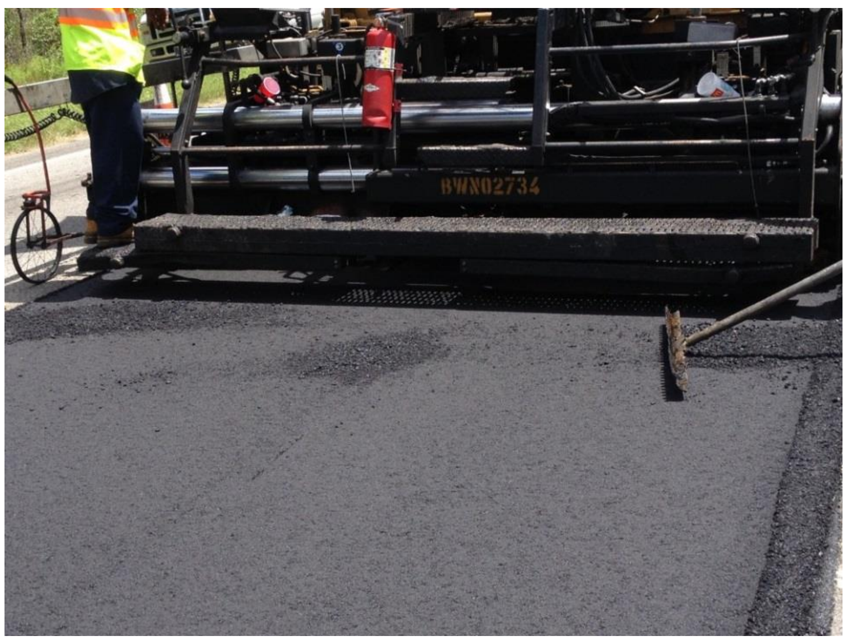

FIGURE 12: Typical Repair Being Made of Sampled Area from Paved Mat

FIGURE 13: Close Quarters for Auger Sampling

STATISTICAL ANALYSIS

A combination of statistical analysis methods was performed on the test data to determine the main effects on the experiment and the contributing factors to test data variability. This analysis was conducted using Minitab statistical software v.17. Analysis of Variance (ANOVA) was used to evaluate factors contributing to variability of sample results. An analysis was made for the No. 8 sieve, No. 200 sieve, asphalt binder content, air voids of plant-compacted samples, and specific gravity (Gmm and Gmb). Contractor test results were included and used as the control sample where needed since FDOT usually compares acceptance test results to the contractor's results. Although open-graded and dense-graded mixes were sampled, they were separated for the analysis.

In order to normalize the data, it was decided to consider the deviation of test values from the Job Mix Formula (JMF) target value. This would eliminate some of the project-to-project variability caused by different mixes being used with different target values. However, even when sample deviation from the JMF alone was evaluated, the analysis showed that the project variability was still the most significant factor affecting test results. This can be explained in that gradation may be easier to control depending on aggregate source and the effectiveness of the contractor quality control program. It was also discovered air voids and specific gravity of mixtures varied more where limestone aggregate was used in mixture production.

DENSE-GRADED MIXES

The test results from Friction Course mixes (FC-5) were separated from analysis of dense graded mixes because the gradation is very different The ANOVA of results providing a comparison of the deviation for percent passing the No. 8 sieve, Table 2, shows the data evaluated by project and by sampling location. This was done to provide an idea of how much variability was still caused by project variation even though the results were normalized by considering sample deviation. However, the focus of this study is the effect of sampling location and only the effect of sampling location will be given for the remainder of the analyses.

The effect of sample location on the deviation from No. 8 sieve target values was not statistically significant as indicated by a p-value of 0.115. At a 95% confidence level, a p-value less than 0.05 indicates significance. Grouping of the sample mean deviations by location using the Dunnett Method shows that the samples taken from the mat were similarly grouped. The ANOVA shows an overall standard deviation of mean sample deviations from the JMF target values of 1.863.

A Two-Sample T-Test was also used to compare the mean and standard deviation of all four sampling locations and determine whether their may be a significant difference in any individual location. The Contractor's test results were used as the control in this case since FDOT makes comparisons with contractor data for validation of test results. The results in Table 3 show there is no significant difference (P-Value > 0.05) between the contractor's test results of samples from a loaded truck at the plant and the three FDOT samples taken at the plant and roadway.

TABLE 2: General Linear Model:
Deviation from JMF on No. 8 Sieve versus Projects, Sample Location

Factor	Type	Levels	Values
Projects	fixed	11	1, 2, 3, 5, 6, 8, 9, 10, 11, 13, 14
Location	fixed	4	Contr@Plant, DOT@Plant, Mat, Auger

Analysis of Variance for Deviation, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Projects	10	269.035	269.035	26.903	7.75	0.000
Location	3	21.847	20.969	6.990	2.01	0.115
Projects*Location	30	74.971	74.971	2.499	0.72	0.851
Error	128	444.189	444.189	3.470		
Total	171	810.041				

S = 1.86285   R-Sq = 45.16%   R-Sq(adj) = 26.74%

Grouping Information Using Dunnett Method and 95.0% Confidence

Location	N	Mean	Grouping
Contr@Plant(control)	43	0.70114	A
DOT@Plant	43	0.97341	A
MAT	43	0.02871	A
Auger	43	0.41242	A

TABLE 3. Two-Sample T-Test: Deviation from JMF on No. 8 Sieve vs Sample Location (For P-Value, Comparisons made to Contractor Results)

Location	Mean Difference	Std. Deviation	P-Value
Contractor@Plant	0.69	2.15	
DOT@Plant	0.97	2.12	0.547
Mat	0.01	1.95	0.127
Auger	0.40	2.42	0.553

The ANOVA for deviation of percent passing the No. 200 sieve, Table 4, showed a significant difference between plant and roadway test results. The P-value of 0.002 as well as the Dunnett Method of grouping shows a difference at the 95% confidence level. The higher deviation values for roadway samples may be due to breakdown of aggregates from additional handling during the hauling, transfer, and placement operations. The mean standard deviation of all results is 0.324. The mean deviation of the contractor's samples was 0.004 while the mean value of mat and auger samples was 0.23 and 0.25, respectively.

TABLE 4. General Linear Model: Deviation from JMF on No. 200 Sieve vs Sample Location

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Factor    Type   Levels  Values
Location  fixed       4  Contr@Plant, DOT@Plant, Mat, Auger

Analysis of Variance for Deviation, using Adjusted SS for Tests

Source             DF   Seq SS   Adj SS  Adj MS      F      P
Location            3   1.6473   1.5874  0.5291   5.03  0.002

S = 0.324199   R-Sq = 77.08%   R-Sq(adj) = 69.38%

Grouping Information Using Dunnett Method and 95.0% Confidence

Treat               N      Mean  Grouping
Contr@Plant        43  0.004091  A
DOT@Plant          43  0.146818  A
Mat                43  0.230758
Auger              43  0.247803

Means not labeled with letter A are significantly different from control level
mean.
```

Since sampling location was found to be a significant factor, a Two-Sample T-Test was performed with the test results of the contractor at the plant used as the control for comparison. The Two-Sample T-Test for deviation of results passing the No. 200 sieve, Table 5, indicates that the mean deviation for the roadway samples was higher than the plant samples. This analysis shows mat samples were insignificant (P-Value >0.05) while the auger samples were significant. However, the mean deviation of roadway samples is still well within acceptance tolerances of ± 1.0%.

TABLE 5. Two-Sample T-Test: Deviation from JMF on No. 200 Sieve vs Sample Location (For P-Value, Comparisons made to Contractor Results)

Location	Mean Difference	Std. Deviation	P-Value
Contractor@Plant	0.00	0.48	
DOT@Plant	0.15	0.60	0.224
Mat	0.24	0.64	0.097
Auger	0.25	0.60	0.037

Project 13 initially skewed the analysis for asphalt content because asphalt contents ranged from 5.53% to 7.20%. The first sublot on the day samples were taken was significantly lower than the results for the remaining sublots. For that reason, an evaluation for outliers was performed using Minitab software and the outlier plot, Figure 14, clearly shows contractor test results from the first sublot was indeed an outlier. The three samples taken by FDOT in the first sublot were also very close to the outlier and were significantly different from the rest of the results for that lot. This large variation in asphalt content would also have an impact on average Gmm, Gmb, and air void determination. For that reason, the results from the first sublot of project 13 were removed from the remaining analysis.

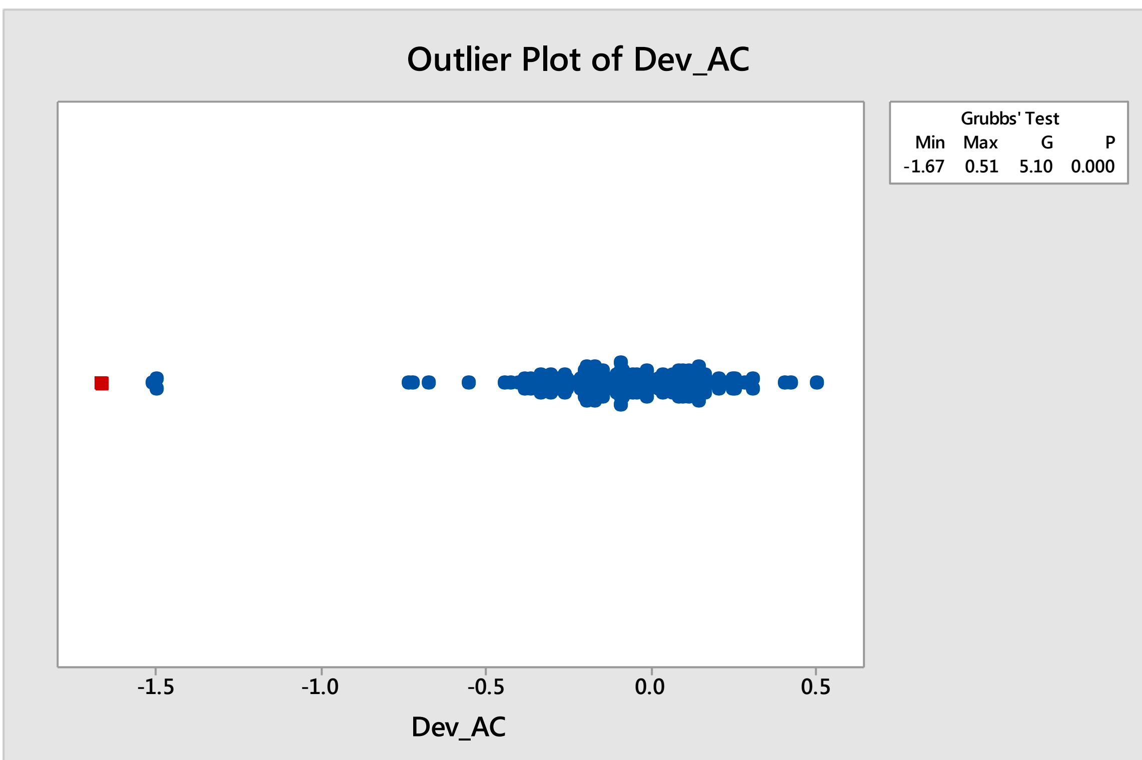

FIGURE 14. Outlier Plot of Asphalt Deviation from JMF Target Values

The ANOVA for deviation in test results for asphalt content, Table 6, shows sample location was not a significant factor affecting the results (P-Value = 0.060). The standard deviation of test results was 0.173. The Two-Sample T-Test results provided in Table 7 shows the highest mean deviation was in samples from the mat behind the paver. However, the P-Values were greater than 0.05 for each location and indicate the difference is not significant.

TABLE 6. General Linear Model: Deviation of AC from JMF vs Sample Location

```
Factor    Type   Levels  Values
Projects  Fixed      11  1, 2, 3, 5, 6, 8, 9, 10, 11, 13, 14
Location  Fixed       4  Auger, Cont, MAT, Plant


Analysis of Variance

Source          DF  Adj SS   Adj MS  F-Value  P-Value
  Location       3  0.2257  0.07522     2.52    0.060
Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0.172835  39.86%     34.79%      28.46%
```

TABLE 7. Two-Sample T-Test: Deviation of Asphalt Content from JMF vs Sample Location (For P-Value, Comparisons made to Contractor Results)

Location	Mean Difference	Std. Deviation	P-Value
Contractor@Plant	0.038	0.18	
DOT@Plant	0.026	0.21	0.792
Mat	0.121	0.19	0.042
Auger	0.067	0.26	0.552

An additional material property used in the calculation of composite pay factor is the air voids of plant-produced, laboratory-compacted samples. In this study, the air void (Va) deviation from the JMF target was compared based on sample location and aggregate type. In this case, the ANOVA, Table 8, showed the sampling location was not significant, but the difference in aggregate type was a significant factor affecting the results. The large amount of error indicates factors other than sample location and aggregate type may be influencing results as well.

The aggregates used on the projects in this study were either granite or limestone. The limestone is well known to have higher absorption which allows asphalt binder to permeate a higher proportion of aggregate particle surface pores. This will in turn affect the maximum mix specific gravity (Gmm) of the loose mix and the bulk specific gravity of the compacted mix (Gmb).

TABLE 8. General Linear Model: Air Voids Deviation from JMF Based on Location, Agg Type

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Location	3	2.373	0.7910	1.11	0.347
AggType	1	10.866	10.8664	15.23	0.000
Error	163	116.301	0.7135		
Lack-of-Fit	3	3.584	1.1945	1.70	0.170
Pure Error	160	112.717	0.7045		
Total	167	129.541			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.844691	10.22%	8.02%	4.58%

Since aggregate type significantly affected air void deviation, test results for air void deviation from JMF target values were separated based on aggregate type. An ANOVA was then performed for both granite and limestone mixes. The ANOVA for granite mixes, Table 9, shows that the mean standard deviation was 0.752 and that sample location was not a significant factor. The ANOVA for limestone mixes (Table 10) also showed that sample location was not significant (P-Value > 0.05); but the standard deviation for air void deviation of limestone mixes is higher than for granite mixes (0.935 vs 0.752). Based on these results, the specification tolerance for air voids will need to be increased from 1.2 to 1.24 for granite mixes and 1.54 for limestone mixes.

TABLE 9. General Linear Model: Air Void Deviation from JMF: Granite vs Sample Location

Factor	Type	Levels	Values
Location	Fixed	4	Cont@Plant, DOT@Plant, Mat, Auger

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Location-G	3	0.0781	0.02603	0.05	0.987
Error	88	49.7282	0.56509		
Total	91	49.8063			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.751727	0.16%	0.00%	0.00%

TABLE 10. General Linear Model: Air Void Deviation from JMF: Limestone vs Sample Location

```
Factor     Type   Levels  Values
Location   Fixed       4  Cont@Plant, DOT@Plant, Mat, Auger

Analysis of Variance

Source        DF  Adj SS  Adj MS  F-Value  P-Value
  Location-L   3   5.879  1.9595     2.24    0.091
Error         72  62.989  0.8749
Total         75  68.868


Model Summary

       S   R-sq  R-sq(adj)  R-sq(pred)
0.935335  8.54%      4.72%       0.00%
```

Two-Sample T-Tests were performed of air voids for each aggregate type and analyzed based on sampling location as well (Table 11) except in this case results were compared to the deviation of contractor's test results which were used as control samples. Based on this analysis, results of the standard deviation were similar and results based on sampling location were not significantly affected by the granite aggregate type (P-Value > 0.05). The same comparison with mixes that used limestone aggregate showed a higher standard deviation when compared to the contractor's results. The analysis also showed that the roadway results for mat samples were significantly different from the contractor's test results on projects where limestone aggregate was used.

TABLE 11. Two-Sample T-Test:
Va Deviation from JMF vs Location by Aggregate Type
(For P-Value, Comparisons made to Contractor Results)

Aggregate	Location	Mean	Std Dev	P-Value
Granite	Contr@Plant	0.19	0.66	
	DOT@Plant	0.12	0.84	0.753
	Mat	0.14	0.73	0.804
	Auger	0.18	0.77	0.966
Limestone	Contr@Plant	0.11	0.76	
	DOT@Plant	0.54	1.20	0.183
	Mat	0.80	1.14	0.029
	Auger	0.67	1.24	0.097

When comparing individual test results of samples of plant-produced mixes, FDOT compares both the Maximum Specific Gravity (Gmm) of loose plant mix and the Bulk Specific Gravity (Gmb) of lab-compacted mix. The Anova for Gmm, Table 12, shows that sampling location did not significantly affect the deviation of Gmm values (P-Value =0.924). A Tukey Pairwise Comparison in Figure 15 also shows consistency when comparing all sampling locations. For the Tukey analysis, since the value of 0.000 is within the range of each comparison, there is not a significant difference in results based on sample location.

However, the ANOVA in Table 12 shows aggregate source was very significant (P-Value 0.000) in determining deviation of test results for Gmm. For this reason, Gmm was then analyzed based on aggregate type used on each project. Of the 11 projects that used dense-graded mix, there were 6 projects with granite aggregate and 5 projects with limestone aggregate.

TABLE 12: General Linear Model: Gmm Based on Aggregate Source, Sample Location

```
Factor  Type   Levels  Values
Agg     fixed       2  Gran, LS
LOC     fixed       4  Cont@Plant, DOT@Plant, Mat, Auger

Analysis of Variance for Gmm, using Adjusted SS for Tests

Source    DF   Seq SS   Adj SS   Adj MS       F      P
Agg        1  0.86329  0.86374  0.86374  575.55  0.000
Location   3  0.00068  0.00071  0.00024    0.16  0.924
Agg*LOC    3  0.00064  0.00064  0.00021    0.14  0.935
Error    163  0.24462  0.24462  0.00150
Total    170  1.10923

S = 0.0387392   R-Sq = 77.95%   R-Sq(adj) = 77.00%

Grouping Information Using Tukey Method and 95.0% Confidence

Agg    N   Mean  Grouping
Gran  92  2.506  A
LS    79  2.363    B

Means that do not share a letter are significantly different.

Grouping Information Using the Tukey Method and 95% Confidence

Location      N     Mean  Grouping
Contr@Plant  43  2.44247  A
DOT@Plant    42  2.43845  A
Mat          43  2.44247  A
Auger        43  2.44086  A
Means that do not share a letter are significantly different.
```

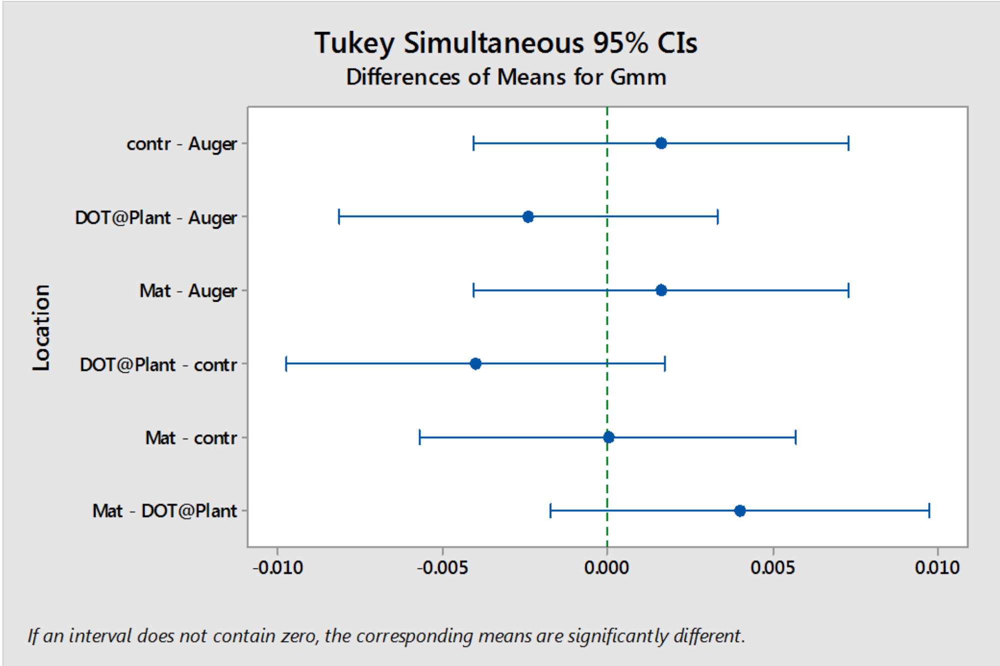

Figure 15. Tukey Pairwise Comparisons: Response = Gmm, Term = Location

Since the Gmm results were significantly different based on aggregate type used in the mix, the results were separated by aggregate type and evaluated based on the deviation of test results from the JMF target value. The ANOVA for the granite mixes, Table 13, shows the sampling location was not a significant factor (P-Value > 0.05) affecting the deviation in Gmm values for granite mixes.

Likewise, Table 14 shows there is not a significant difference in deviation of Gmm values for limestone mixes (P-Value > 0.05) depending on sample location. However, the standard deviation is slightly higher than for granite mixes.

The difference in mean values for Gmm of limestone (2.363) compared to granite (2.506) explain why aggregate type was shown in Table 12 to be a significant factor affecting test results. However, when only the deviation in test results from JMF target values is considered, Tables 13 and 14 show deviation of Gmm is not significantly affected by sample location.

TABLE 13. General Linear Model: Gmm Deviation from JMF for Granite Mixes vs Sample Location

```
Factor        Type   Levels  Values
Location     Fixed       4  Cont@Plant, DOT@Plant, Mat, Auger

Analysis of Variance

Source        DF    Adj SS    Adj MS   F-Value  P-Value
Location       3  0.000461  0.000154     0.97    0.410
Error         88  0.013949  0.000159
Total         91  0.014411

     S       R-sq  R-sq(adj)  R-sq(pred)
0.0125903  3.20%      0.00%       0.00%
```

TABLE 14. General Linear Model: Gmm Deviation from JMF for Limestone Mixes vs Sample Location

```
Factor        Type   Levels  Values
Location     Fixed       4  Cont@Plant, DOT@Plant, Mat, Auger

Analysis of Variance

Source        DF    Adj SS    Adj MS  F-Value  P-Value
Location      3   0.000795  0.000265     0.60    0.616
Error         75  0.033029  0.000440
Total         78  0.033824

     S      R-sq     R-sq(adj)  R-sq(pred)
0.0209855  2.35%      0.00%       0.00%
```

A Two-Sample T-Test was performed (Table 15) to compare deviation of Gmm values from the JMF target for tests taken by FDOT as compared to those deviations of the contractor Gmm from JMF values. The data was separated by aggregate type and sampling location. The comparison shows the standard deviation of results was slightly higher for samples from limestone projects, but deviations were not significantly different based on sample location.

TABLE 15. Two-Sample T-Test:
Deviation of Gmm Test Value from JMF Target
vs Location by Aggregate Type
(For P-Value, Contractor Deviation Used as Control)

Aggregate	Location	Mean	Std Dev	P-Value
Granite	Contr@Plant	-0.020	0.012	
	DOT@Plant	-0.019	0.011	0.746
	Mat	-0.024	0.013	0.209
	Auger	-0.021	0.014	0.778
Limestone	Contr@Plant	-0.019	0.015	
	DOT@Plant	-0.009	0.019	0.084
	Mat	-0.012	0.023	0.338
	Auger	-0.013	0.023	0.345

Since Gmm values were significantly affected by aggregate type, it was decided to compare the deviation in Gmb from JMF target values based on aggregate type as well. Tables 16 and 17 show that standard deviation of Gmb deviations from JMF target values is slightly higher for mixes with limestone aggregate, but sample location is not a significant factor affecting Gmb deviations. Similar results were obtained when performing the Two Sample T-Test comparing FDOT results to the contractor's results, Table 18. The standard deviation was slightly higher for limestone mixes, but the deviations were not significantly affected by sample location.

TABLE 16. General Linear Model: Gmb Deviation from JMF for Granite Mixes Vs Sample Location

```
Factor   Type   Levels  Values
Location   Fixed       4  Cont@Plant, DOT@Plant, Mat, Auger

Analysis of Variance
Source   DF    Adj SS    Adj MS   F-Value  P-Value
Location  3  0.000432  0.000144     0.63    0.596
Error    88  0.020039  0.000228
Total    91  0.020470

     S      R-sq    R-sq(adj)  R-sq(pred)
0.0150901  2.11%      0.00%       0.00%
```

TABLE 17. General Linear Model: Gmb Deviation from JMF for Limestone Mixes Vs Sample Location

```
Factor        Type   Levels  Values
Location   Fixed       4  Cont@Plant, DOT@Plant, Mat, Auger

Analysis of Variance
Source   DF    Adj SS    Adj MS    F-Value  P-Value
Location   3  0.001180  0.000393     0.99    0.404
Error     72  0.028676  0.000398
Total     75  0.029855

     S      R-sq    R-sq(adj)  R-sq(pred)
0.0199569  3.95%      0.00%       0.00%
```

TABLE 18. Two-Sample T-Test:
Deviation of Gmb Test Value from JMF Target
vs Location by Aggregate Type
(For P-Value, Contractor Deviation Used as Control)

Aggregate	Location	Mean	Std Dev	P-Value
Granite	Contr@Plant	-0.024	0.012	
	DOT@Plant	-0.021	0.015	0.502
	Mat	-0.027	0.016	0.446
	Auger	-0.025	0.016	0.822
Limestone	Contr@Plant	-0.023	0.021	
	DOT@Plant	-0.026	0.019	0.693
	Mat	-0.034	0.019	0.126
	Auger	-0.031	0.016	0.214

Once the effect of various factors was evaluated using an ANOVA, it was determined the percent passing the No. 200 sieve was significantly different based on sample location (Table 4). However, the amount of variability was within acceptable limits. The ANOVA for air voids showed that aggregate type was significant, but the sampling location was found to be an insignificant factor for mixes with granite aggregate. Deviations for limestone mixes were also insignificant when compared to JMF target values; but when FDOT results were compared to contractor results (Table 11) it was found that samples from the mat were a significant factor affecting results.

From the summary information in Table 19, PWL limits can be determined by multiplying the standard deviations by a factor of 1.645 which is the z-value multiplier that represents the number of standard deviations needed to encompass 90% of the test results for a minimum 1.0 pay factor. The pay factor for each material property is calculated using Equation 1 and results are provided in Table 20. The calculated specification limits from this study indicate that deviation from air voids for granite materials is marginally outside the 2014 specification values. Calculated specification limits for air voids from limestone aggregate mixes are substantially outside the 2014 specification limits and will need to be increased to ±1.6 if roadway samples are to be used for acceptance.

TABLE 19: Summary of ANOVA Results - Dense Mixes

Property	P-Value	Std Dev
No. 8 Sieve	0.115	1.863
No. 200 Sieve	0.002	0.324
AC, %	0.060	0.173
Air Voids, %		
Granite	0.987	0.752
Limestone	0.091	0.935
Gmm		
Granite	0.410	0.013
Limestone	0.511	0.020
Gmb		
Granite	0.596	0.015
Limestone	0.336	0.019

Pay Factor = [55 + (0.50 × PWL)] / 100 **Equation 1**

TABLE 20: Determination of Specification Limits

Property	Mean Std Dev	Calc. Spec Limits	2014 Spec Limits
% Passing No. 8 Sieve	1.863	3.06	± 3.1
% Passing No. 200 Sieve	0.324	0.53	± 1.0
% AC	0.173	0.28	± 0.4
Air Voids			
Granite	0.752	1.24	± 1.2
Limestone	0.935	1.54	±1.2

The Master Production Range (MPR) is calculated by multiplying the mean standard deviation by a factor of 3.0 in order to encompass at least 99% of the population. In Table 21 a comparison was made between the range tolerances established prior to PWL as reported in 2001 (Sholar et al, 2005), and the revised values in 2004 (Sholar et al, 2006) to the calculated MPR for the test data in this study. Based on data from this study, the Master Production Range will need to be re-evaluated for air voids.

TABLE 21: Comparison of Master Production Range

Material Property	This Study	2001*	2004*
% Passing No. 8	5.59	± 5.50	± 5.50
% Passing No. 200	0.97	± 1.50	± 1.50
% AC	0.52	± 0.55	± 0.55
Air Voids, % (Granite)	2.26	±1.5	+2.0,-1.7
Air Voids, % (Limestone)	2.81	±1.5	+2.0,-1.7

*(Sholar, et al, 2006)

Another comparison that was needed was to compare contractor results of samples taken from a truck at the plant to the results of FDOT samples taken from the same truck. This comparison was needed in order to compare how well the current FDOT verification process of contractor test results related to the results from this study. This comparison was made by determining the standard deviation of the differences between contractor and FDOT plant results, then multiplying that value by 2.0 in order to determine acceptable tolerances for individual test results at a 95% confidence level (Table 22).

TABLE 22: Comparison of Contractor Quality Control and FDOT Verification Data Based on Plant Samples

	This Study			2002 (Sholar, et al, 2006)		
Material Property	Avg Diff QC - DOT	Std Dev of Diff	Individual Test Tolerance, ±	Avg Diff QC - DOT	Std Dev of Diff	Individual Test Tolerance, ±
% Passing No. 8 Sieve	0.28	1.387	2.77	-0.30	2.10	4.12
% Passing No. 200 Sieve	0.14	0.41	0.82	-0.07	0.50	0.99
% AC	-0.01	0.149	0.30	-0.04	0.18	0.35
Gmm (Granite)	0.001	0.007	0.014	-0.001	0.010	0.019
Gmb (Granite)	0.003	0.008	0.016	-0.001	0.010	0.020
Gmm (Limestone)	0.009	0.016	0.032			0.019
Gmb (Limestone)	0.004	0.011	0.022			0.020

The 2002 comparison represents the tolerances used in the 2014 specifications. The comparison from this study shows that contractor and FDOT test results from this study generally are in closer agreement than in 2002 when the PWL specification was first revised except for specific gravity results of limestone mixes. Based on results from this study, Gmm and Gmb individual test tolerances for limestone mixes should be increased to account for differences between contractor and FDOT samples taken at the plant.

Since FDOT is considering using roadway samples for acceptance and verification of contractor test results, it was necessary to also compare roadway sample test results to the contractor's plant sample. Therefore, the data was evaluated to determine the acceptable variability when the mat samples and auger samples were compared to contractor plant results (based on values from FDOT test method FM 1-T 030). The comparison (Table 23) shows there is more variability between the plant sample taken by the contractor and the roadway samples from both the paver auger and the finished mat where limestone aggregates are used. This higher variation is likely a result of additional binder absorption into the aggregate particle, and having to reheat the roadway samples for lab testing. If roadway samples are taken to verify contractor test results at the plant, the tolerances for limestone mixes need to be increased for Gmm and Gmb values. The additional tolerance is needed to account for absorption and possible effect of reheating of the sample. Tables 22 and 23 show that the test tolerance for Gmm of limestone mixes should be increased from ±0.016 to ±0.032. The test tolerance for Gmb of limestone mixes should be increased from ±0.022 to ±0.026.

TABLE 23: Comparison of Contractor Quality Control and FDOT Verification Data Based on Mat and Auger Samples

	Compare Contractor QC to Mat			Compare Contractor QC to Auger			Current Test Tolerance ±
Material Property	Avg Diff QC - Mat	Std Dev of Individual Diff	Individual Test Tolerance ±	Avg Diff QC-Auger	Std Dev of Individual Diff	Individual Test Tolerance ±	
% Passing No. 8 Sieve	0.682	1.854	3.71	0.294	2.233	4.47	4.50
% Passing No. 200 Sieve	-0.23	0.496	0.99	-0.247	0.505	1.01	1.3
% AC	0.083	0.173	0.35	0.029	0.221	0.44	0.44
Gmm (Granite)	0.005	0.007	0.014	0.001	0.008	0.016	0.016
Gmb (Granite)	0.003	0.010	0.020	0.001	0.009	0.018	0.022
Gmm (Limestone)	0.006	0.014	0.028	0.006	0.012	0.024	0.016
Gmb (Limestone)	0.011	0.012	0.024	0.010	0.013	0.026	0.022

OPEN-GRADED MIXES (FC-5)

An analysis of FC-5 mixtures was performed similarly to the analysis for dense-graded mixes. Although only two FC-5 projects were sampled, the data represents eight tests from each sample location. A statistical ANOVA (Table 24) revealed that both the project and sample location were significant at the 95% confidence level (P-Values < 0.05). The Dunnett method of comparison evaluates the variability of sample means when compared to results from a control sample. Contractor samples taken at the plant were used as the control results for the Dunnett comparison.

Table 25 shows that samples from the mat behind the paver were significantly different for the percent passing the No. 4 sieve and for asphalt content. The samples taken from the auger of the paver were significantly different for the percent passing the No. 8 sieve.

TABLE 24. Summary of ANOVA Results for FC-5 Mixes

	Location				
Property	Seq SS	F-Value	P-Value	Std Dev	R^2, %
3/8 in Sieve	134.73	4.17	0.015	3.28	57.7
No. 4 Sieve	33.01	3.46	0.032	1.783	48.9
No. 8 Sieve	4.673	3.07	0.047	0.712	86.9
AC, %	1.11	5.50	0.005	0.259	85.9

TABLE 25. Dunnett Method of Comparison for FC-5

Property	Contr	DOT-Plant	DOT-Mat	DOT-Auger
3/8 in Sieve	A	A	A	A
No. 4 Sieve	A	A		A
No. 8 Sieve	A	A	A	
AC, %	A	A		A

The mean standard deviations for the two projects were used to determine specification limits for a standard 90 PWL. The calculated value for specification limits based on sample results failed to meet the current tolerances for percent passing the 3/8 in sieve for the contractor's sample at the plant as well as for the sample from the roadway mat (Table 26). The auger samples failed to meet current tolerances for percent asphalt content. The contractor had one plant sample from project 7 that was approximately 10 percent coarser on the 3/8 in sieve than any of the other sample locations. It is suspected the sample may have been segregated; and if omitted, the calculated specification limit would be 4.05 which compares very closely to the 3.85 value from DOT samples taken at the plant.

It is interesting that the Dunnett method comparison in Table 25 showed the mat samples were different from results of the other sample locations, but the calculated specification limit is actually higher for the auger samples. This is because the mat samples were consistently lower in asphalt content although they had less variability than the auger samples. The average asphalt contents for contractor plant samples, DOT plant samples, and mat and auger roadway samples were 6.14, 6.16, 5.70, and 6.07, respectively.

TABLE 26. Specification Limits for FC-5

	Contractor-Plant		DOT- Plant		Mat		Auger		
Property	Mean Std Dev	Calc. Spec Limits	Mean Std Dev	Calc. Spec Limits	Mean Std Dev	Calc. Spec Limits	Mean Std Dev	Calc. Spec Limits	Current Spec Limits
% Passing 3/8 in Sieve	3.689	6.07	2.342	3.85	3.700	6.09	1.780	2.93	±6.0
% Passing No. 4 Sieve	2.251	3.70	1.461	2.40	1.672	2.75	1.365	2.25	±4.5
% Passing No. 8 Sieve	0.527	0.87	0.774	1.27	0.578	0.95	0.853	1.40	± 2.5
% AC	0.17	0.28	0.25	0.41	0.25	0.40	0.30	0.49	± 0.45

The high calculated specification limit for the 3/8 in sieve from roadway mat samples was due to one sample from project 4 that was about 12 percent coarser than samples from the other locations. If that one sample were omitted, the calculated specification limit would be 5.12.

CONCLUSIONS

As a result of the agency survey of sampling locations and the field testing performed for FDOT projects, several conclusions can be made.

- There is approximately the same number of agencies taking acceptance samples from the plant as from the roadway.
- Agencies typically use the same test tolerances for roadway samples as for plant samples although very few formal comparisons have been made or reported.
- Formal and informal studies indicated the standard deviation of test results for both plant and roadway sampling are usually well within the specification tolerances currently being used.
- When agencies allow either roadway or plant sampling, the overwhelming preference is for plant sampling due to reduced logistical issues and providing more timely results.
- When roadway samples are taken, 75% of the time samples are taken behind the paver. A metal template or plate may, or may not, be required.
- Sampling from the paver auger may be safer than mat sampling at the roadway because technicians can sample from the side of the paver away from live traffic and no one has to walk on the hot mat. This also does not impact smoothness since roadway repairs and paver stops are not necessary.
- Roadway sampling is sometimes limited based on mix type, layer thickness, or project quantities/size.
- Sampling from a MTV, if used, has several benefits including safety, not having to stop the paving operation, and it takes advantage of any remixing accomplished by the MTV.
- The ANOVA of field data for dense-graded mixes showed sample location was generally not significant except for air voids and mixture specific gravity.
- The percent passing the No. 200 sieve may be higher for roadway samples due to handling and transfer of materials during the placement/paving operation. In this study, deviation of test results was higher for roadway samples than for plant samples. Deviation of auger samples was found to be significant based on a Two-Sample T-Test comparison with the contractor samples taken at the plant, but the variability was within specification tolerances.
- Asphalt content of roadway samples may be lower than plant samples. This could be caused by additional absorption during transport from the plant to the roadway so technicians may not be able to completely remove all the binder during the extraction procedure, or it may be that some of the binder adhered to the tacked roadway surface.
- Individual test tolerances for air voids, Gmm and Gmb of dense-graded mixes were found to be significantly affected by aggregate type. When limestone aggregate is used, the tolerance for those properties should be increased. This will allow for additional binder absorption and any effect of reheating samples.
- Air voids of laboratory compacted samples taken from the mat of limestone projects were statistically different than air void results of mix taken at other locations.

- The specification limits calculated based on the mean standard deviation of various test results for this study were in conformity with the 2014 specifications except for air voids. The results for granite mixes were marginally outside current limits (1.24 vs 1.2), but there was a considerable difference in air voids deviations of limestone mixes (1.54 vs 1.2).
- A comparison of contractor quality control results at the plant and FDOT verification tests from the roadway show that Gmm test tolerances will need to be increased for limestone mixes to 0.032. Gmb tolerances will need to be increased to 0.026.
- The ANOVA for FC-5 mixtures showed sampling location was a significant factor affecting test results at a 95% confidence level.
- The Dunnett method of comparison for FC-5 mixes showed roadway mat and paver auger samples were significantly different from plant sample results of both contractor and DOT. Therefore, roadway sampling is not recommended for FC-5 mixes.

In summary, roadway samples may be used for acceptance or verification of contractor test results using current limits and tolerances with the exception of air voids and specific gravity of limestone mixes. Tolerances for each of those categories will need to be increased if roadway samples are to be used for comparison or acceptance.

RECOMMENDATIONS

As part of this study, a survey and review of agency asphalt sampling information was conducted along with field samples taken for comparison with current Specification tolerances. This study considered sampling from three locations. Plant sampling was conducted as the standard for comparison to roadway sampling since the current specifications were developed for plant sampling. A statistical evaluation of the project samples from the roadway mat and paver auger was conducted in this study and compared to standard specification tolerances used currently by FDOT. Recommendations from this study are:

- Mat samples taken from either the paver auger or finished mat behind the paver may be used for acceptance and verification with the same confidence as current specifications except for air voids, Gmm, and Gmb where limestone aggregates are used. The individual test tolerance for Gmm for samples of limestone mixes should be increased to at least 0.032, and Gmb tolerance for limestone mixes should be increased to 0.026.
- The calculated specification limit for air voids should be increased to ±1.8 for limestone mixes.
- A metal plate is not recommended when sampling from behind the paver. The size of metal plates needed to obtain adequate sample mass as well as the cumbersome process of handling and maintaining the plates will likely make this practice burdensome for FDOT.

- Based on the ANOVA and Dunnett method showing significant differences for both mat and auger samples compared to plant results, it is recommended roadway samples not be used for acceptance of FC-5 mixtures.

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APPENDIX A

Florida DOT Roadway Sampling Survey

State	Question 1: Acceptance samples may be taken from?	Question 2: Describe Roadway Procedure.	Question 3: Any restrictions for roadway sampling?	Question 4: Same tolerances for plant vs roadway?	Question 5: If sampled behind the paver, how are repairs made?	Question 6: Economic incentives for sampling from roadway?	Question 7: If sampling from road, what previous method did you change from and why?	Other Comments?
Alabama	Truck Only			N/A				
Alaska	Roadway Only	Use metal plate or windrow (AASHTO T168)	May use other methods for small quantities/ thin layers	N/A	Immediately by contractor	Not aware of any.	Plant before 1990s. Statistical sampling believed to be better at point of placement.	Fear of adding roughness not a problem; more roughness happens when paver stops.
Arkansas	Plant or Roadway	Roadway samples not typically taken. Sample full depth with shovel or sampling device.	No	Same deviation	Fill in with shovel	N/A		
Arizona	Roadway (except OGFC)	Use 4' x 1' metal plate placed ahead of paver. Sample one shovel width from center of plate. Place additional plates if a larger sample is needed.	No OGFC from roadway. Sample OGFC at plant in 3 places 12" below the surface.	N/A	Fill in with shovel	No	N/A	
California	Roadway (except OGFC)	4 locations transversely across the mat	No OGFC from roadway	N/A	Fill in with shovel. If depressions effect smoothness, those areas are omitted.	N/A		OGFC not sampled from road due to difficulty in making repair without effecting smoothness.
Colorado	Plant, windrow, auger, uncompacted mat.	Roadway samples not typically taken. 1/2 of windrow width at $\geq$ 3 locations: 3 equal increments from auger (minimize loss of larger particles).	Augers 2/3 full, operating $\geq$ 80% of time.	Same deviation; no report	Samples from behind the paver not typically taken.	Only depends on location of lab in relation to lay-down.		
Connecticut	Truck Only							Did a few in-house experiments from roadway; but never implemented due to patching needed, and safety concerns.
D.C.	Behind the paver	Take one sample with shovel at random location	No	N/A	Normal patching method.	No	Always have sampled from roadway.	Have compared QA from roadway to QC at the plant, but no significant differences. No report.

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Delaware	Truck only	N/A	N/A	N/A	N/A	N/A	N/A	Sampling procedures mention use of AASHTO T168, but samples always taken at plant.
Florida	Truck only							
Georgia	Allows plant or roadway sampling	Allows either, but Roadway samples not typically taken.	No OGFC from roadway	Same deviation; no report	Fill in with shovel	N/A		Sample width in 3 sections; wait until 1/2 of load has been dumped.
Hawaii	Allows plant or roadway sampling	Place metal plate completely across the mat, and shovel mix from the plate.	No	Yes. No formal comparisons made, but it seems Gmm at the plant runs lower than from road.	Normal patching method; smoothness not affected.	No	Still use either although behind the paver is used most often due to more representative sample (MTV used).	
Idaho	Typically from Roadway	Place a template into finished mat and sample from the template. Take as many samples as needed to get the required sample size.	Yes, If layer thickness is <0.2' (about 2.5"), sample from truck at the plant	N/A	Normal patching.	No	Changed from roadway only to allow plant samples for thin layers due to size of dug-out area in the mat that was needed to get adequate sample size.	Have allowed plant samples for thin layers for 2-3 years. Considering switching to plant samples altogether.
Indiana	Behind the paver	Uses metal plates with different sizes depending on sample size needed. Plates are placed ahead of paver (may be nailed down to keep from sliding).	Thickness must be >2 x NMAS at the sample location, or another location is selected.	Did a comparison study several years ago; checking on report.	Normal patching method; smoothness not affected.	No	Used to sample at plant about 15 years ago, but changed due to belief that most representative sample is of in-place material.	MTV not required, but is often used.
Illinois	Roadway only	May be from four samples taken transversely behind the mat, or from MTV where MTV conveyor is swung over to shoulder and mix dumped into a splitter device. Samples from behind the paver are taken at quarter points diagonally across the mat over a 10' length.	No	N/A	Replaced material is mounded up so roller won't bridge over a depressed area.	Not documented, but believe it saves money because it doesn't require a technician at the plant.	Used truck samples until about 3 years ago. Roadway sampling recommended by FHWA.	MTV method is preferred because it doesn't affect the mat.

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Iowa	Behind the paver	Use metal templates behind the paver and scoop out mix within the template frame. Sample diagonally over a 30 tons distribution area at 1' from each side and 1' on each side of screed centerline. Sample from both quarterpoints if more material is needed.	No	N/A	Normal patching method; smoothness not affected.	No	Been sampling from roadway > 35 years.	Complaints from contractors, but nothing shows method is detrimental to the paving operation.
Kansas	Behind the paver	Insert template into uncompacted mix; take sample from each wheelpath, then move up about 10' and sample between wheelpath.	No	N/A	Normal patching method; smoothness not affected.	No	Plant before 2002. Statistical sampling believed to be better at point of placement.	
Kentucky	Truck only	N/A	N/A	N/A	N/A	N/A	N/A	
Louisiana	Truck only	N/A	N/A	N/A	N/A	N/A	N/A	Currently conducting a couple of research projects to compare roadway to plant samples.
Maine	From paver hopper	Sample the paver hopper like sampling a stockpile; then split samples with a quartering device.	No	N/A	N/A	Believe so; it eliminates having a technician at the plant full-time.	Switched from truck sampling about 15 years ago. In-house study compared truck sampling, from the paver hopper, and behind the paver; saw no significant difference (report not available).	QC samples at the plant; QA samples at the roadway.
Maryland	Behind the paver	Use metal plate and shovel from the plate.	No. The procedure is used on all QC/QA projects (>200 tons).	N/A	Normal patching method; smoothness not affected.	No	Switched a long time ago due to belief sample is more representative.	
Massachusetts	Truck only							
Michigan	Roadway Only	Samples 6" from edge of pavement on each side, and one sample from center of mat. Take samples diagonally over a 10' length.	For trench widening, dump some material in a small stockpile and sample.	N/A	Normal patching method; some initial complaints, but generally smoothness not affected.	No, but believe it is safer since technicians do not have to climb into the truck.	Truck at plant; switched about 10 years ago in order to get more representative sample.	

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Minnesota	Plant or roadway; contractor's option.	Sample at one spot according to random location.	No	Yes. No formal comparisons made, but limited in-house sampling did not reveal any significant differences.	Normal patching method; smoothness not affected.	May be cheaper to sample at the plant (easier logistically). Believed to be safer at the plant also since technicians will not be working around traffic.	N/A	Changed from roadway only to allow truck sampling this year due to desire for timely test results.
Mississippi	Truck only							
Missouri	TSR samples taken at plant (due to sample size); but volumetric samples taken from behind the paver.	Sample from single location at random. Some contractors use a metal plate; others do not.	Low volume mixes sampled for AC content at the plant.	N/A	Normal patching method; smoothness not affected.	No	Been using roadway sampling for about 13 years. Believe it is most representative of final product.	Contractors complained initially, but no evidence that smoothnesss or performance are affected.
Montana	Plant or roadway; contractor's option.	Contractor generally takes samples from windrow, or from paver auger chamber. Does not sample behind the paver due to concerns with patching and smoothness.	No	Same tolerances; no comparison has been done.	N/A	No, it probably costs more due to transporting sample to lab and delay in test results.	N/A	Contractor takes samples at location of their choosing, but under DOT supervision.
Nebraska	Roadway only	From windrow or behind paver. Take sample with a shovel and split down to testing size.	No; but if placing a thin layer, contractor usually samples from windrow. This year, began using plant samples only for shoulder mix.	No correlation	Normal patching method; smoothness not affected.	No	Previously from behind paver; began allowing from windrow about 12 years ago.	
Nevada	Behind the paver.	Take 3 samples with shovel transversely across the mat; no template used.	No	No correlation	Normal patching method; smoothness requirements not changed.	No	Previously from windrow; changed to behind the paver about 15 years ago.	Require MTV on all projects.
N. Hampshire	Behind the paver.	Pave over 12" x 12" template; then scoop one shovel sample from the plate.	No	What informal comparisons have been made seem to show the mix is about 2% coarser based on roadway samples.	Normal patching method; smoothness not affected.	No	Sampled from truck at plant up to 15 years ago. Believe behind the paver is more "end result" and most appropriate for QA.	For non-QC/QA projects, they sample from the truck at the plant.
N. Jersey	Truck Only							Believe roadway sampling would be more expensive. Want inspectors at the plant.

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N. Mexico	Roadway only	Started with a template; but that was a lot of trouble, so they just shovel from the roadway.	No	N/A	Fill hole with loose material. Sometimes contractors complain, but they do not adjust smoothness requirements because of this.	No	Changed from windrow to behind the paver about 15 years ago; just want to sample as far in the process as possible.	
N. York	Truck Only							One contractor may produce the mix and another place it. Roadway sampling would create issues determining which contractor is responsible for differences.
N. Carolina	Truck Only							Tried roadway sampling on one project, but more advantageous to sample at plant. Concerned about roughness from sampling at road.
N. Dakota	Gradation based on cold feed samples at the plant; eveerything else based on sample behind the paver.	Use shovel; no template	No	N/A	Normal patching method; smoothness not affected.	No	Have used roadway sampling for a long time.	AC content from ignition method of roadway samples; but afraid gradation may be affected by breakdown during the burn process, so use cold feed for gradation.
Ohio	Truck only	Used a metal plate and shoveled sample from the plate.	Samplesd from the paver hopper for thick layers such as Base or Binder.	N/A	Normal patching method, but there were concerns for smoothness and performance.	No; believe more experienced technicians, and ability to get more consistent samples, are at the plant.	Changed to plant sampling due to safety and segregation issues, and many complaints from contractors.	FHWA continues to recommend sampling from behind the paver.

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Oklahoma	Truck Only							Too much delay in getting results; can't use results for plant adjustment. Concerned for smoothness and effect of roadway segregation.
Oregon	Roadway only	Sample from Windrow.	No	N/A	N/A	No	N/A	Don't sample behind the paver due to smoothness concerns.
Pennsylvania	Behind the paver	Scoop sample off roadway.	Do not sample small projects if < one Lot, or for scratch courses.	N/A	Normal patching method; smoothness not affected.	No	Been sampling from roadway > 30 years.	
Puerto Rico	Plant only	N/A	N/A	N/A	N/A	No	Sampled from road up to about 5 years ago, but changed due to contractor complaints about effect on smoothness.	
Rhode Island	Plant only	N/A	N/A	N/A	N/A	No	N/A	Considering a trial project to look at sampling behind the paver.
S. Carolina	Truck Only							1980 in-house study (no report available) showed sampling from spreader hopper was most consistent. Stopped due to safety concerns and contractor complaints about effect on smoothness of stopping paver operations.
S. Dakota	Roadway Only	Contractor given option to sample from windrow or behind the paver. Most sample from the windrow due to concerns sampling from the mat may affect smoothness.	No	N/A	Normal patching method; smoothness not affected.	No	Used to sample from behind paver only; but due to contractor concerns that it may affect smoothness, they now allow windrow samples.	

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Tennessee	Truck only	N/A	N/A	N/A	N/A	No	N/A	
Texas	Truck only	Roadway sampling allowed only after special approval. Roadway sampling is from paver auger.	Special approval needed.	Yes	N/A	No; due to logistics issues it will likely cost more.	N/A	
Utah	Behind the paver, except surface mix sampled from truck due to smoothness concerns.	Use a template to eliminate effect of tack coat.	No	Not looked into truck sampling.	Use care in patching to minimize roughness.	Not aware of any.	Have used roadway sampling for a long time.	
Vermont	Mainly from truck, but roadway allowed (used about 5% of time).	Sample with shovel behind paver.	No	Same tolerances. No report, but they believe variability is the same.	Use care in patching to minimize roughness.	Not aware of any.	Only sample from road when necessary; not the normal procedure.	
Virginia	Truck Only							Concerned about safety and smoothness when sampling behind paver.
Washington	Truck Only							Sample size (100 lb) too large to take from road without affecting smoothness.
West Virginia	Truck Only; but plan to test from road on a few projects in 2013	Sample with shovel behind paver.	No	Plan to use same tolerances; no study.	Use care in patching to minimize roughness.	Don't foresee a benefit; may result in more effort for district offices.	Believe roadway sampling will be better for PWL by providing more accurate measure of in-place properties.	Some concern that roughness may increase with roadway sampling.
Wisconsin	Truck Only							Have considered sampling behind the paver, but decided not to due to concerns for safety, smoothness, and performance.
Wyoming	Roadway only	Sample from windrow. Remove the top few inches of the windrow and sample similar to truck sampling.	No	N/A	N/A	No	Used to take sample from auger, but changed due to safety concerns.	Have tried sampling from behind the paver on a few projects, but believe that method created more problems than it solves.