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DETERMINE PROPER SELECTION OF RIDE QUALITY PAY ADJUSTMENT SCHEDULE AND RE-EVALUATION OF CURRENT BONUS/PENALTY STRUCTURE: TECHNICAL REPORT

Technical Report 0-6986-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

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16. Abstract

The Texas Department of Transportation (TxDOT) currently uses a guidance document to help select a ride quality pay schedule for paving projects. This guidance is more than 15 years old and was developed without a robust dataset. This project used more than 300 highway projects to categorize paving projects into eight groups. Following categorization, post-construction ride quality was analyzed from hundreds of sections within each group. Based on post-construction data, a data-driven guidance document was developed, and modifications to the existing TxDOT Item 585 pay structure were proposed. The data-driven approach used post-construction expectations to construct pay structures for each work group that have large bonuses for superior pavements and large penalties for rough pavements. This improved incentive and disincentive structure was developed because the industry currently achieves bonuses on 80 percent of paved sections. While statewide ride quality is currently smooth, particularly for asphalt surfaces, the current structure in the specification will not lead to statewide ride quality improvement. The proposed structure provides expectation-based incentives and disincentives high enough to improve statewide ride quality for each work group. The proposed guidance document should be used for informational purposes to understand expectations for post-construction smoothness and predict post-construction smoothness when preconstruction data are present. However, implementing the guidance document for pay schedule selection should only occur in conjunction with pay structure changes in the specification.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Charles F. Gurganus, P.E. #101096.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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INTRODUCTION

Each year, the Texas Department of Transportation (TxDOT) lets and constructs a diverse portfolio of paving projects. The annual letting includes between 300 and 400 projects eligible for ride quality measurements. Of that number, between 10 percent and 12 percent are concrete projects, while the remainder are asphaltic surfaces. In TxDOT's Standard Specifications, Item 585: Ride Quality for Pavement Surfaces provides the smoothness requirements for paved surfaces constructed during a construction or maintenance project. For the current research project, a paved surface does not include projects with surface treatments as the final riding surface.

Following construction, contractors perform ride quality testing on the finished paved surface using inertial profilers. This procedure is governed by Item 585 within the Standard Specifications, and testing and test equipment must comply with test method Tex-1001-S. Measurements are consolidated into a .PRO file processed within TxDOT's Ride Quality software. The output of the Ride Quality software consists of inertial roughness index (IRI) values (in./mi.) in each wheel path on 0.1-mi. data collection sections. Bonus or penalty amounts are applied to each data collection section based on the average wheel path IRI, localized roughness, assigned pay schedule, and pay adjustments outlined in Item 585.

Item 585 consists of three different pay schedules from which to choose. To assist designers and districts with selecting the proper pay schedule, TxDOT's Construction Division produced a guidance document in 2004. This guidance document, along with the bonus and penalty structure of Item 585, has remained unchanged. Since 2004, paving contractors and paving equipment have improved to construct smoother pavements, particularly hot-mix asphalt (HMA) surfaces. Also, many TxDOT districts have taken advantage of newer mixes constructed in thinner lifts (i.e., thin overlay mixtures [TOM] or thin-bonded friction courses). Changes have also occurred for concrete pavements. Special Specification 3012: Next Generation Concrete Surface (NGCS) Grinding was instituted to improve ride quality on concrete surfaces. This technique has been deployed as a maintenance action on existing concrete surfaces and a smoothness improvement technique on newly constructed concrete pavements.

These changes and the elapsed time since the creation of the guidance document served as the impetus for this research project. During the project, the research team synthesized the selection and enforcement of Item 585 across Texas. During this synthesis, the team also evaluated and summarized the use of the existing guidance document. Following the review of current practices, the team analyzed post-construction ride quality data on 70 paving projects, consisting of 8,448 data collection sections. Using this analysis, the research team established data-driven post-construction ride quality expectations for eight different construction scopes. Using these new expectations, the research team created a new, simpler guidance document to help districts with the selection of pay schedules. After the creation of the new guidance document, the research team proposed changes to the bonus/penalty structure of Item 585 that would better reward contractors capable of placing smooth pavements and was more punitive toward rougher pavements. The research team also reviewed whether prescribing a more stringent pay schedule led to smoother final surfaces. Finally, the research team undertook an analysis to determine whether it was appropriate to have a different pay schedule specifically for concrete surfaces. The remainder of the report steps through the tasks in detail.

CONDUCT A SYNTHESIS OF RIDE QUALITY SELECTION AND ENFORCEMENT

Item 585 has two different testing methods to evaluate ride quality:

- Test Type B serves as the default test type and requires the contractor to use a high-speed or lightweight inertial profiler. In addition to defaulting to Test Type B, the specification defaults to Pay Schedule 3.
- Test Type A uses a 10-ft. straightedge (a profiler can also be used) to evaluate ride quality. Test Type A typically applies to areas where smooth ride quality would be difficult to achieve (i.e., short paving pulls of less than 2,500 ft.) or where ride quality is not as important (i.e., shoulders, ramps, or bridges). The use of Test Type A does not include a bonus/penalty structure.

To assist with the selection of a pay schedule, TxDOT's Construction Division produced a guidance document in 2004. The guidance document contains a table with the information shown in Table 1. The term *smoothness opportunity* in Table 1 occurs on a construction project when continuous construction at a depth of 1.0 inches takes place. This includes overlays, in-place recycling, and grading for base courses.

In order to evaluate statewide ride quality selection, enforcement, and agreement with the existing guidance document, all fiscal year (FY) 2018 paving projects were evaluated for ride quality selection. In addition to the FY 2018 paving projects, a sampling of FY 2016 and FY 2017 paving projects was reviewed to determine if the trends identified from FY 2018 projects expanded to other years.

Table 1. Existing TxDOT Guidance Document (TxDOT Construction Division Memo 2004).

Project DescriptionB2:F16				Recommended Pay Adjustment Schedule
New Construction or major Rehabilitation (IH, US, Multilane divided highways)	Rigid Pavements	Continuosly Reinforced Concrete Pavement (CRCP)		2
		Jointed Concrete Pavement (JCP)		3
	Flexible Pavements with a total HMA thickness > 1.5"			1
Overlays or Minor Rehabilitation	Rigid Pavements (bonded and unbonded concrete overlay)			3
	Flexible Pavements with total HMA thickness < 1.5" such as an overlay with a Permeable Friction Course (PFC). Note that in some cases Surface Test Type A may be more appropriate for this application.			3*
	Flexible Pavements Total HMA thickness > 1.5"	All roads with posted speed < 45MPH		3*
		When there are 2 or more smoothness opportunities	All highway classifications other than 2-lane undivided	1*
			2-lane undivided highways	2*
		When there is only 1 smoothness opportunity	All highway classifications other than 2-lane undivided	2*
			2-lane undivided highways	3*

* It may be appropriate to increase or decrease this number depending on the ride quality of the existing pavement. For example: if the ride quality of the existing pavement is poor (IRI>170), it may be appropriate to increase this number if applicable. Conversely, it may be appropriate to decrease this number if applicable and if the ride quality of the existing pavement is good (IRI<95).

FY 2018 RIDE QUALITY SELECTION

During FY 2018, 348 paving projects were let. The typical sections for each of these projects were reviewed to identify the surface type, lift thickness, and opportunities for improvement. Using this information, a pay schedule as suggested by the guidance document was selected and compared with the actual pay schedule chosen. Information gathered from these typical sections was used later in the project to categorize typical construction techniques used in paving projects. This categorization helped give the new guidance document a structure based on construction technique, a topic discussed later in this report. Table 2 and Figure 1 summarize the results for FY 2018 paving projects.

For FY 2018, 65 percent of projects prescribed a pay schedule that coincided with the guidance document. When a discrepancy existed between the guidance document and the pay schedule selected, a less stringent pay schedule was typically chosen. For FY 2018 paving projects, just over 10 percent were concrete pavements. The random selection of projects from FY 2016 and FY 2017, discussed later in this report, included 11.5 percent concrete projects. Table 2 also shows that in FY 2018, TxDOT produced approximately 74 percent of paving plans in house, though some districts like Abilene exclusively used consultants.

Table 2. FY 2018 Paving Project Summary.

District	Total Projects	Surface Type		Pay Schedule			Guidance Document Agreement			Design	
		Asphalt	Concrete	1	2	3	Yes	No, More Stringent	No, Less Stringent	TxDOT	Consultant
Abilene	12	12	0	1	3	8	7	2	3	0	12
Amarillo	9	8	1	3	6	1	7	1	1	8	1
Atlanta	11	11	0	0	4	7	6	0	5	11	0
Austin	18	18	0	2	4	12	15	2	1	15	2
Beaumont	17	15	2	2	6	9	9	2	6	11	6
Brownwood	4	4	0	4	0	0	3	1	0	3	1
Bryan	11	11	0	1	4	6	7	2	2	11	0
Childress	7	6	1	1	3	3	7	0	0	6	1
Corpus Christi	16	15	1	6	8	2	12	1	3	12	4
Dallas	27	17	10	3	10	14	17	2	8	20	7
El Paso	4	4	0	1	2	1	2	0	2	3	1
Fort Worth	22	19	3	0	6	16	12	4	6	17	5
*Houston	31	21	10	1	14	14	20	3	8	25	6
Laredo	7	6	1	5	2	0	6	1	0	5	2
Lubbock	7	7	0	4	3	0	7	0	0	7	0
Lufkin	9	9	0	2	2	5	8	0	1	7	2
Odessa	15	15	0	6	6	3	7	1	7	8	7
Paris	5	4	1	3	2	0	3	2	0	3	2
Pharr	12	12	0	6	2	4	6	0	6	11	1
San Angelo	11	10	1	2	4	5	10	1	0	8	3
**San Antonio	27	23	4	5	8	8	13	1	13	13	14
***Tyler	20	20	0	2	2	12	6	4	10	15	5
Waco	16	16	0	3	9	4	11	1	4	10	6
Wichita Falls	12	12	0	1	0	11	7	0	5	11	1
Yoakum	18	17	1	10	8	0	18	0	0	16	2
Totals	**348**	**312**	**36**	**74**	**118**	**145**	**226**	**31**	**91**	**256**	**91**

* The total number of projects in the Houston District is more than the sum of the pay schedules due to maintenance contracts that could have used Pay Schedule 3 but did not use Item 585.

** The total number of projects in the San Antonio District is more than the sum of the pay schedules because a number of contracts waived the ride when it could have been enforced.

*** The total number of projects in the Tyler District is more than the sum of the pay schedules because a number of projects should include the ride specification, but it was not activated in the estimates, though it is not waived by general note.

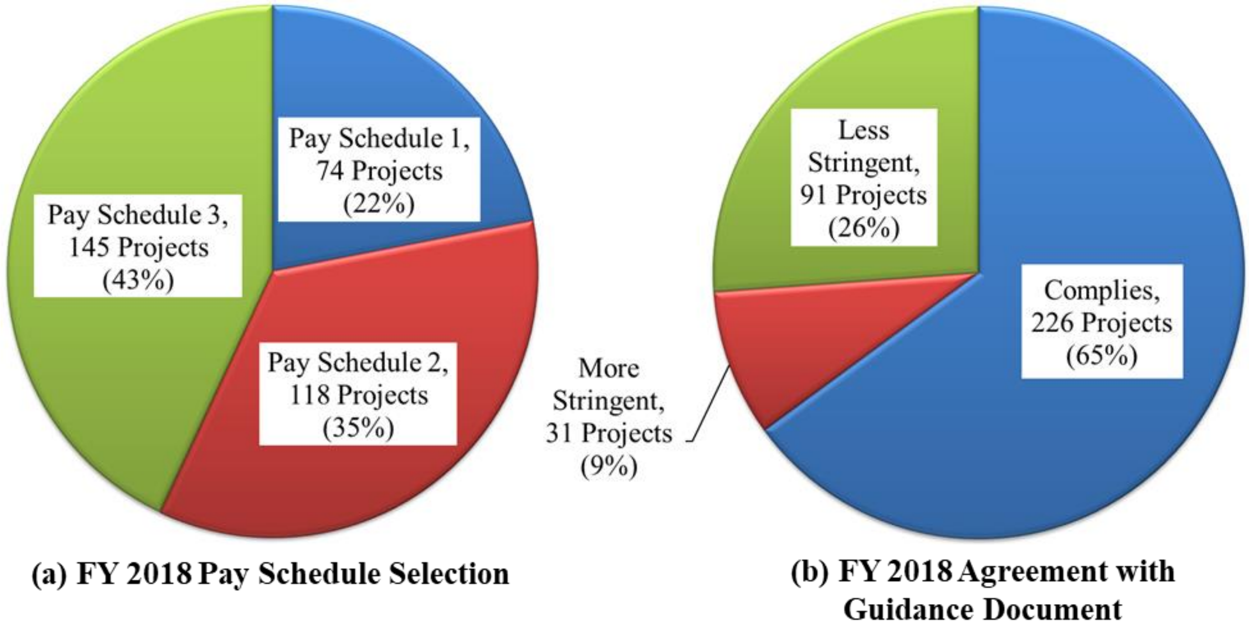

Figure 1. FY 2018 Pay Schedule Summary.

Because the surface type was identified for each FY 2018 project, a residual outcome of this task was the identification of pavement surface type used in each district. Table 3 displays this information, while Figure 2 visually displays the number and percentage of each surface type on a statewide level. Superpave (Item 344) was the most commonly selected surface, followed by dense graded (Item 341). Of the designer asphalt mixes, stone matrix asphalt (SMA) was the most common, followed by TOM and then permeable friction course (PFC). The Lubbock and Austin Districts rely heavily on designer mixes, with the Lubbock District selecting an SMA surface on all seven paving projects. This constituted almost 14 percent of all SMA use in the state. Of the 18 paving projects let in the Austin District, each used either TOM or PFC, with several projects having both. The Austin District comprised 44 percent of statewide TOM use in FY 2018. As expected, the Houston and Dallas Districts had the most concrete surfaces, with each district letting 10 concrete projects, making up more than 50 percent of statewide concrete projects.

Table 3. FY 2018 Pavement Surface Type by District.

District	Total Projects	Surface Type: Item 341 (Dense Graded)	Item 342 PFC	Item 344 Superpave	Item 346 SMA	Item 347 TOM	Item 348 Thin Bonded Surface	Item 360 Concrete
*Abilene	12			7	6			
Amarillo	9			8				1
Atlanta	11			5	6			
*Austin	18		5			17		
Beaumont	17	4		8	4	1		2
Brownwood	4	1		3				
*Bryan	11		3	8	2	1		
Childress	7	6						1
*Corpus Christi	16	5		5	4		2	1
Dallas	27		1	14	2			10
*El Paso	4			4		1		
Fort Worth	22	11		4	2	2		3
Houston	31	11	3			7		10
*Laredo	7			7				1
Lubbock	7				7			
Lufkin	9		4	4		1		
Odessa	15			6	3	6		
Paris	5	4						1
Pharr	12	4		4	4			
*San Angelo	11		1	11				1
*San Antonio	27	5	1	15	2	1	1	4
*Tyler	20		6	10			4	1
*Waco	16	6	3		6	2		1
*Wichita Falls	12	5	1	2	3		1	1
Yoakum	18	14	3					1
Totals	**348**	**76**	**31**	**125**	**51**	**39**	**8**	**39**

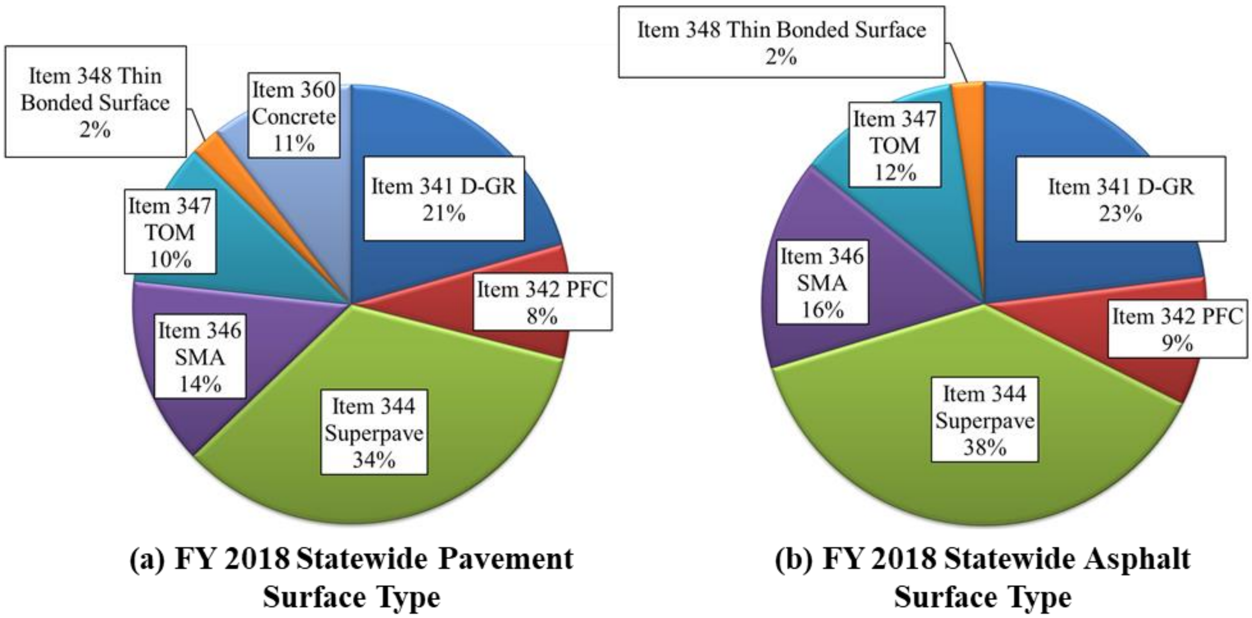

Figure 2. FY 2018 Paving Type Summary.

As previously mentioned, since 2004, many changes have occurred within the paving industry, particularly to flexible pavements. A couple of options now exist to lay surface mixes thinner than 1.5 in., which, based on the existing guidance document, is not a smoothness opportunity. Nonetheless, smooth rides are achieved, and districts are enforcing Item 585. In FY 2018, 33 paving projects in 14 districts constructed a final HMA surface with a thickness of less than 1.5 in. Of those 33 projects, the following pay schedules were chosen:

- Pay Schedule 3 for 25 projects.
- Pay Schedule 2 for 5 projects.
- Pay Schedule 1 for 1 project.
- Waived/no enforcement for 2 projects.

The project with Pay Schedule 1 comes from the San Antonio District (0142-14-061) and included hot-in-place-recycling (HIR) and a 1-in. TOM overlay. While HIR constitutes a smoothness opportunity, the final 1 in. of new asphaltic surface limits the project to Pay Schedule 3 using the existing guidance document. The San Antonio District also waived the ride quality on a 1-in. TOM overlay project (0215-021-043). Many of the other thin-lift projects included pure overlays with a mat thickness less than 1.5 in. For example, the Lufkin District constructed three projects (0200-01-083, 0059-03-020, and 0177-01-103) with either 0.75 in. of TOM or 1.25 in. of PFC. Each project enforced Pay Schedule 3 and paid a bonus. The Corpus Christi District let a project with only a 0.75-in. thin-bonded wearing course overlay (0617-01-196) and specified Pay Schedule 2. This is an example of guidance document disagreement with a more stringent pay schedule selected.

Several thin overlay projects in the Houston District presented confusing information. A project (0976-01-039) included a 1-in. TOM overlay and a general note indicating Pay Schedule 2; however, Item 585 was not activated in the estimate. Similarly, another 1-in. TOM project in the Houston District (0178-01-036) specified Pay Schedule 3, but the item was not activated in the estimate. These two projects also display how a district can have very similar projects and select two different pay schedules.

During the analysis of FY 2018 projects, several general notes were discovered that contradicted the guidance document. For example, five projects in the San Antonio District waived the ride quality requirement through a general note, yet the scope of work implied the need to enforce Item 585. Details of these projects are provided in Appendix A: Guidance Document Discrepancies.

These Item 585 issues were not isolated to the San Antonio District. The specification is written in a way that Item 585 defaults to the bonus/penalty structure unless otherwise stated (at least for main lanes). However, the Tyler District had several projects (0123-03-021, 0206-03-061, 0191-03-081, and 0191-01-063) where no general note was included, and no item was activated despite the scope of work implying the need for smoothness evaluation. In the synthesis, these were noted as disagreements with the guidance document because the assumption was made that Item 585 would not be enforced, therefore representing a less stringent selection.

The Beaumont District seemed to have two consultant designs let in July 2018 (0200-11-095 and 0739-02-162) that carried a general note outlining different pay schedules for asphalt lanes, concrete lanes, curb and gutter (C&G) sections, and outside lanes in C&G section even though many of those parameters did not apply to the scope of construction. This issue is less concerning than waiving the ride quality altogether although it further justifies the need to update the guidance document and educate districts on its use.

FY 2016–FY 2017 RIDE QUALITY SELECTION AND ENFORCEMENT

For FY 2016 and FY 2017, 15 percent of paving projects were randomly selected, resulting in the analysis of 96 paving projects, 85 of which had an asphaltic surface and 11 of which had a concrete surface. Table 4 compares the findings of the FY 2018 analysis with the findings using randomly selected projects from FY 2016 and FY 2017. The similarities shown in Table 4 validate the conclusions drawn from using the FY 2018 data.

Table 4. FY 2018 Findings Compared with FY 2016–FY 2017 Findings.

	Pay Schedule Selection			Guidance Document Comparison		
	Pay Schedule 1	Pay Schedule 2	Pay Schedule 3	Agrees	Less Stringent	More Stringent
FY 2018	22%	35%	43%	65%	26%	9%
FY 2016 - FY 2017	23%	33%	44%	58%	26%	16%

EXISTING GUIDANCE DOCUMENT AGREEMENT SUMMARY

TxDOT maintains a diverse paving portfolio. TxDOT typically lets 10 to 12 percent concrete projects, while the remainder are asphaltic surfaces, totaling between 300 and 400 annual paving projects. Disagreement exists between the selection of a pay schedule and guidance provided by the existing guidance document. The analysis showed that projects with similar scopes of work have different pay schedules within the same district. The project review uncovered confusing general notes or what appeared to be carryover notes from a previous project with a different paving scope. The evolution of thinner mixes also plays a role in the need to re-evaluate ride quality enforcement. Many districts are constructing overlay projects with HMA thickness of less than 1.5 in. and occasionally less than 1.0 in. while enforcing Item 585. Most of these projects used Pay Schedule 3, though some used Pay Schedule 2 despite the guidance document's note to use Pay Schedule 3 or Test Type A when HMA thickness is less than 1.5 in. Data are now available to develop a data-driven guidance document while accounting for project scope and typical preexisting conditions for a given project scope. The remainder of this report details the development of the new guidance document.

INVESTIGATE RIDE QUALITY IMPROVEMENT OF DIFFERENT TYPES OF PAVING PROJECTS

The existing guidance document considers many variables to assist decision makers with pay schedule selection. This approach was prudent in 2004 before vast amounts of data existed to inform TxDOT on what it should expect for final smoothness given a specific work action.

An analysis was performed on the final IRI values for different types of paving construction. While each paving project is unique, through the analysis of all FY 2018 paving projects and a review of post-construction IRI values on 70 other projects, researchers found that a typical type, or scope, of construction could be assigned to most of the paving projects. A project could use more than one of the eight project types identified. When this occurs, the potential exists for TxDOT to prescribe different pay schedules for different lanes within a project, a practice currently used and accomplished through general notes. Also, unique features could exist in a project that does not neatly fit into one of the eight groups. While this occurs, it is the exception, not the rule, and the most similar construction scope should be used to determine post-construction expectations. The eight construction scopes identified as typical paving work on projects are:

1. Group 1: Mill and fill in the outside lane of a C&G section.
2. Group 2: Mill and fill when the mat is not constrained to a gutter pan.
3. Group 3: Scarify and reshape base with an overlay equal to or greater than 1.5 in.
4. Group 4: HMA overlay with a depth greater than or equal to 1.5 in.
5. Group 5: Mill and overlay with a mat thickness deeper than 1.5 in.
6. Group 6: HMA overlay with a depth less than 1.5 in.
7. Group 7: Multiple HMA lifts with a depth greater than or equal to 1.5 in.
8. Group 8: Continuously reinforced concrete pavement (CRCP).

The use of NGCS and SS 3012 was also reviewed but was not included as a specific work type because it already uses a specification and ride structure unique to itself. Post-construction .PRO files for 70 paving projects were processed through TxDOT’s Ride Quality program, resulting in 8,448 data collection sections. This number of data collection sections corresponds with more than 825 lane miles of paving used to develop the new guidance document.

POST-CONSTRUCTION IRI RESULTS

Table 5 shows the average IRI values for each wheel path and the overall average IRI value for each of the eight paving types. Certain trends in Table 5 are intuitive and expected. For example, on mill and fill projects in the outside lane of a C&G section, the left wheel path (i.e., the inside wheel path) rides smoother than the right wheel path (i.e., the outside wheel path). This is expected because of the influence of the concrete C&G on ride quality. While this has been assumed for some time, the magnitude of the impact was not quantified. In the 188 sections associated with this type of work, the smoothness difference across wheel paths exceeded 25 in./mi. Based on this information, on average if bonus/penalty requirements were applied to each wheel path, the right wheel path would receive a penalty (due to the C&G constraint), and the left wheel path would receive a bonus.

Table 5. Average IRI for Different Paving Operations.

Construction Scope	No. of Sections	Average Left Wheelpath IRI (in./mi.)	Average Right Wheelpath IRI (in./mi.)	Average Wheelpath IRI (in./mi.)
Mill & fill in outside lane of C&G	188	55.2	83.0	69.6
Mill & fill not constrained by gutter	535	52.6	57.6	55.1
Scarify & reshape base with overlay ≥ 1.5 in.	228	52.2	55.9	54.1
Overlay ≥ 1.5 in.	4259	45.9	48.1	47.0
Mill & overlay with HMA ≥ 1.5 in.	1805	48.8	49.4	49.1
Overlay < 1.5 in.	918	50.0	53.0	51.5
Multiple lifts of HMA ≥ 1.5 in.	515	35.4	37.4	36.4
CRCP	318	92.9	93.8	93.0

Table 5 further indicates that multiple lifts of HMA paving resulted in the smoothest final surface. Not only is this surface the smoothest, but the difference between left and right wheel path IRIs are minimal. Regardless of work type, the left wheel path always rides smoother, though negligibly in most cases, than the right wheel path. The following paving project list is ordered from smoothest to roughest:

1. Multiple lifts of HMA greater than or equal to 1.5 in. (Group 7).
2. Overlay greater than or equal to 1.5 in. (Group 4).
3. Mill and overlay with HMA greater than or equal to 1.5 in. (Group 5).
4. Overlay greater than or equal to 1.5 in. (Group 6).
5. Scarify and reshape base with overlay greater than or equal to 1.5 in. (Group 3).
6. Mill and fill not constrained by gutter (Group 2).
7. Mill and fill in outside lane of C&G (Group 1).
8. CRCP (Group 8).

Figure 3 shows the histogram and cumulative curve for the average IRI for a mill and fill project in the outside lane. During construction, the smoothness of this lane is constrained by the C&G. While not obvious in Figure 3, Table 5 clearly shows that the wheel path closest to the gutter pan rides much rougher than the inside wheel path. Of all the paving project types, this type of construction has the largest disparity between wheel path smoothness. Figure 3 shows that on average, sections in the outside lane of a C&G project would receive no bonus, and over 15 percent of sections have an IRI above 95 in./mi. The number of deficient sections is larger than the number of sections in any other bin. Only CRCP has more deficient sections than the outside lane of a milled and filled C&G section.

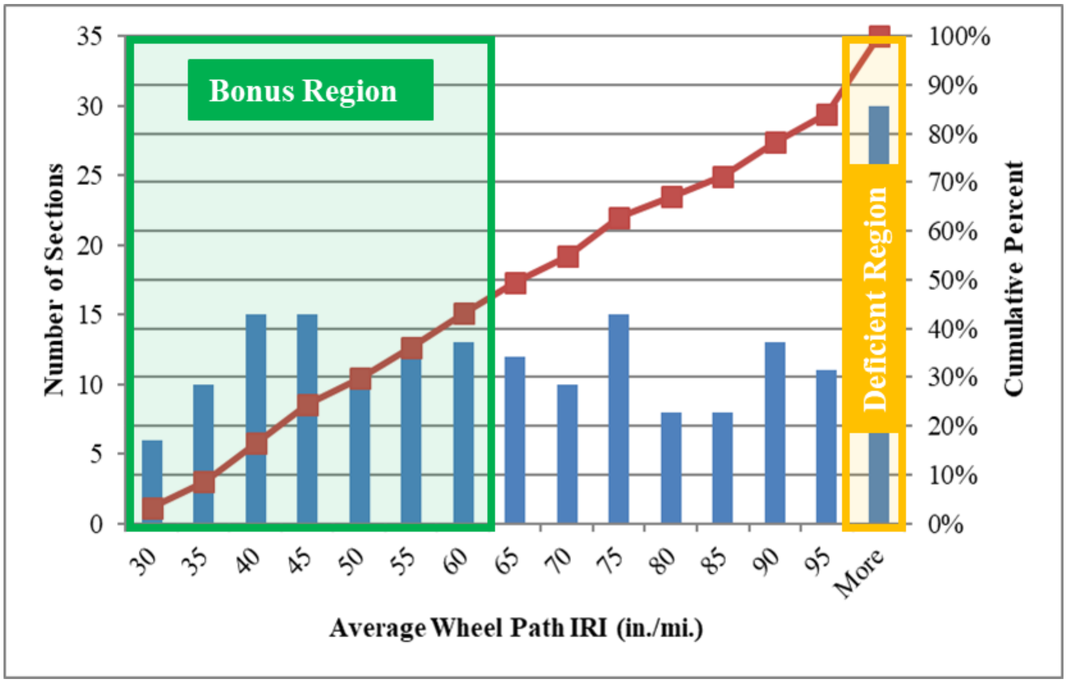

Figure 3. Average Wheel Path IRI for Mill and Fill in Outside Lane of C&G (Group 1).

Figure 4 displays the distributions for mill and fill when the outside edge of the mat is not constrained to a gutter pan. This type of construction is not limited to C&G areas but can include more rural mill and fills where the travel lanes are milled and replaced while not milling the shoulders. A more thorough analysis was performed of increasing smoothness moving away from the confined edge (i.e., the gutter pan). The additional histograms in Appendix B: Post-construction Left and Right Wheel Path IRI Values display the increasing smoothness that occurs moving away from the confining edge. For the lane adjacent to the outside lane, the left wheel path has over 50 percent of sections with an IRI of less than or equal to 45 in./mi. On the other hand, fewer than 30 percent of sections in the right wheel path have the same level of smoothness. These results, along with the wheel path IRI values shown in Table 5 for the outside and inside lane of a C&G section, clearly illustrate that the constraining edge condition severely impacts the ability to create smoothness. However, when multiple opportunities exist moving transversely away from the constraint, high levels of smoothness are attainable. Figure 4 shows that for mill and fill in a lane not constrained by the gutter pan, approximately 70 percent of sections receive a bonus, while fewer than 10 percent of sections are deficient.

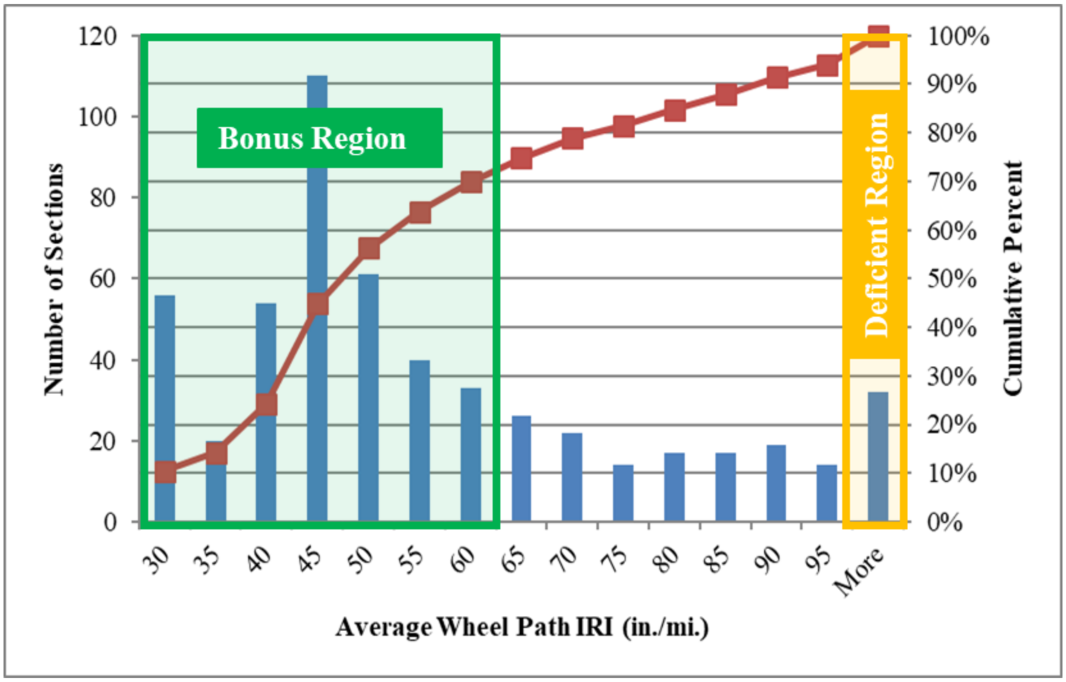

Figure 4. Average IRI for Mill and Fill Not Constrained by Gutter (Group 2).

Figure 5 contains the average IRI distribution for scarifying and reshaping the existing base followed with a single-lift overlay. The distributions, regardless of wheel path, are similar and appear somewhat normal. The middle portions of the distributions are cumulatively linear, particularly between IRI values of 40 in./mi. and 55 in./mi, implying this level of smoothness is attainable on many sections, comprising over 60 percent of all sections. The scarify and reshape projects with an overlay work action have approximately 75 percent of sections in the bonus region with less than 2 percent of sections deficient.

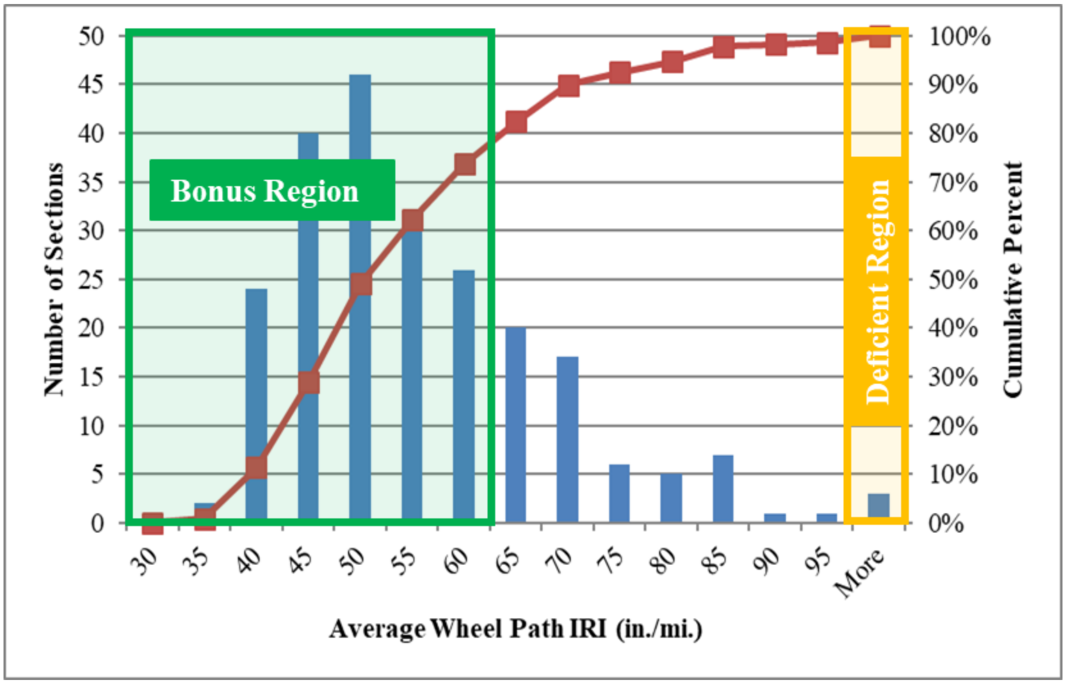

Figure 5. Average Wheel Path IRI for Scarify with Overlay Projects Greater than or Equal to 1.5 in. (Group 3).

Figure 6 shows the distribution for the average wheel path IRI for thick overlays (i.e., a single lift greater than or equal to 1.5 in.). This is the most common work type within TxDOT, constituting approximately 50 percent of the entire paving portfolio and having over two times as many projects as the next closest work type. Construction of single-lift overlays result in smooth pavements, with over 85 percent within the bonus region, approximately 70 percent smoother than 50 in./mi., and fewer than 2 percent of sections deficient.

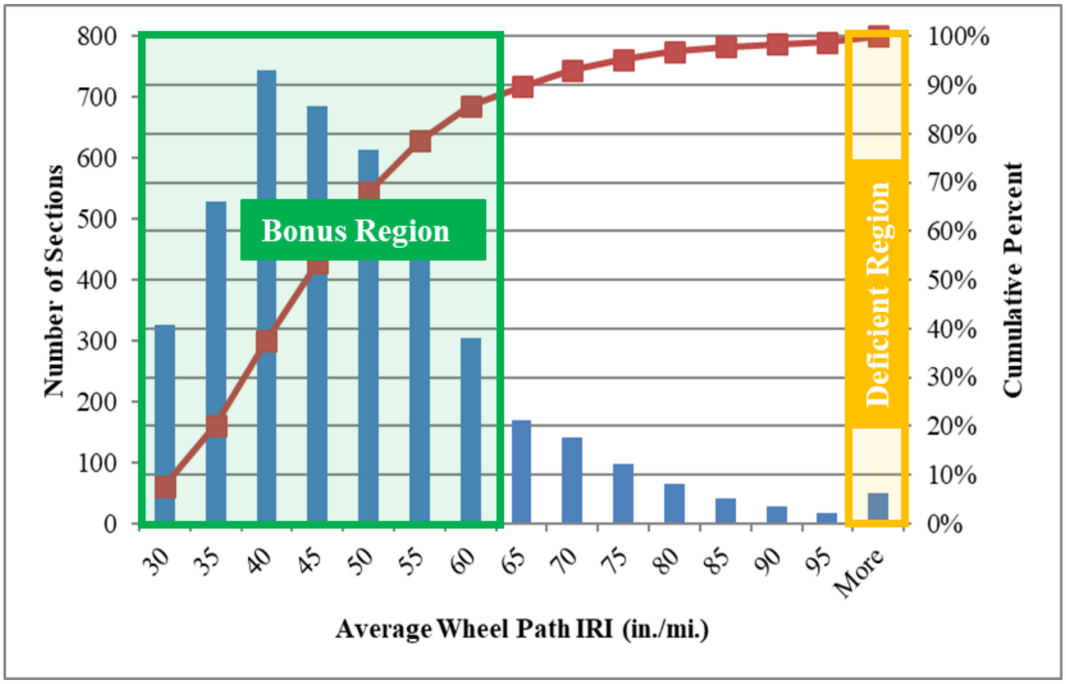

Figure 6. Average Wheel Path IRI for Overlay Greater than or Equal to 1.5 in. (Group 4).

Figure 7 has the distribution for mill and overlay projects where the overlay thickness is at least 1.5 in. This type of work constitutes the second largest work type within TxDOT's paving portfolio, comprising almost 22 percent of paved sections. These distributions were expected to look like the distributions for overlays with a mat thickness of 1.5 in. Comparing Figure 7 with Figure 6 seems to indicate that the pure overlay leads to projects with a smoother surface. While, on average, the IRI values between a pure overlay and mill and overlay project with a similar mat thickness are within 2 in./mi. of each other, a pure overlay produces approximately 20 percent more sections with an IRI less than 40 in./mi. This finding does not imply that milling is not necessary. Milling is often required to reestablish roadway shape, whereas construction of pure overlays often occurs on roadways with better preexisting conditions. The logic used throughout the creation of the new guidance document assumes TxDOT engineers will continue to use the same practices when assigning paving scope to future projects. In other words, while pure overlays using single-lift mats produce over 85 percent of sections in the bonus region, part of the reason this occurs is because of the underlying pavement condition prior to overlay. The engineer cannot assume that this smoothness is attainable regardless of preexisting condition; rather. The work done throughout this research project assumes that TxDOT engineers will continue to select treatment types in the way that it is done now.

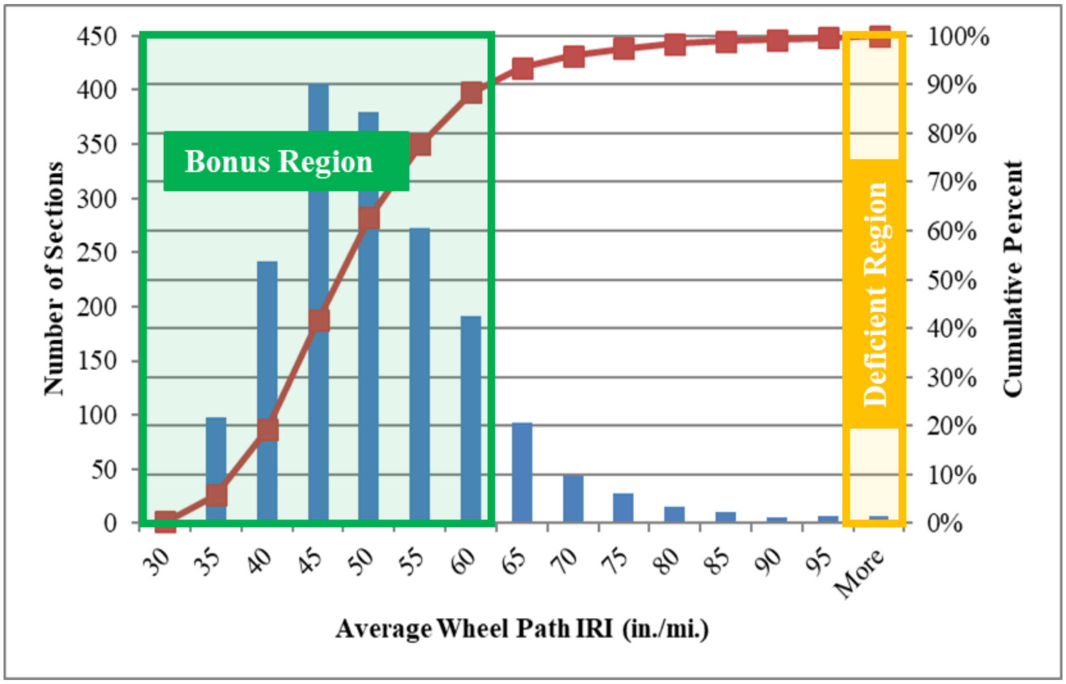

Figure 7. Average Wheel Path IRI Mill and Overlay Greater than or Equal to 1.5 in. (Group 5).

Figure 8 shows the distribution for thin overlays (i.e., less than 1.5 in.). During the synthesis task, researchers discovered that some districts use Test Type A on these projects, assuming the opportunity does not exist for the contractor to achieve enough smoothness to enforce the bonus/penalty aspect of Item 585. Figure 8 shows that almost 80 percent of sections were constructed within the bonus portion of the specification, and less than 5 percent were above 95 in./mi. The ability to achieve this level of smoothness with thin overlays potentially exists because of preexisting conditions, a concept discussed later in this report. The results in Figure 8 indicate TxDOT constructs these pavements in locations where high levels of smoothness can be achieved.

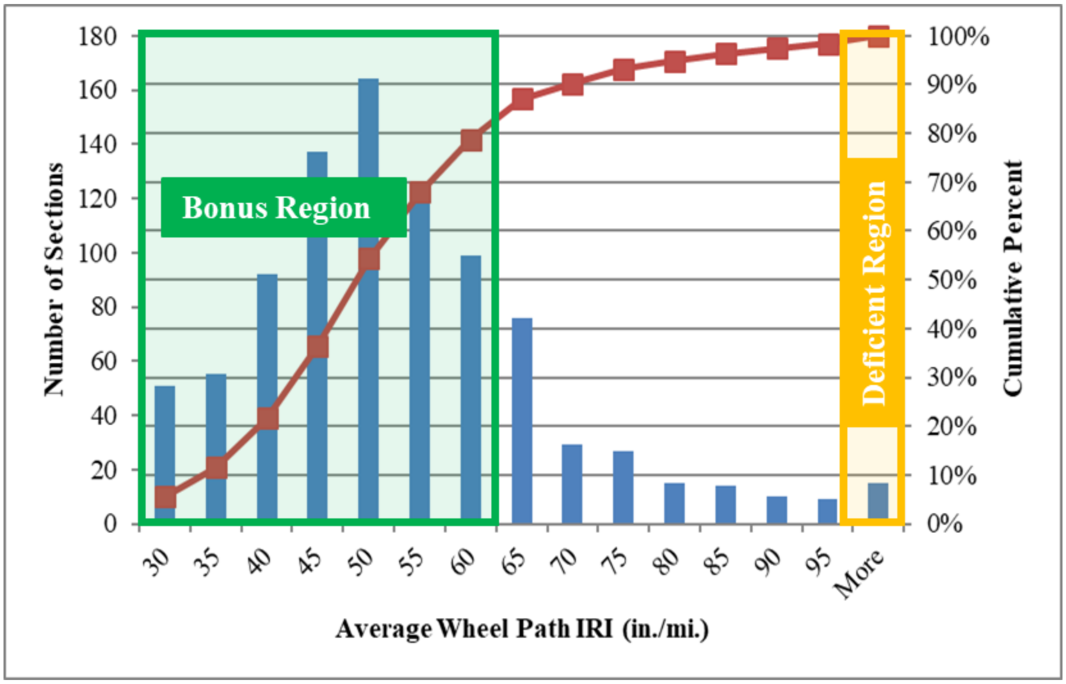

Figure 8. Average Wheel Path IRI for Overlay Less than 1.5 in. (Group 6).

Figure 9 is the distribution for paving projects with multiple lifts of HMA. This type of construction has the most similar distributions across the wheel paths and represents the smoothest IRI values. Over 40 percent of these sections have a final average smoothness of less than 30 in./mi., maximizing the bonus possibility. Almost 99 percent of sections are constructed within the bonus portion of Item 585, and no deficient sections were measured.

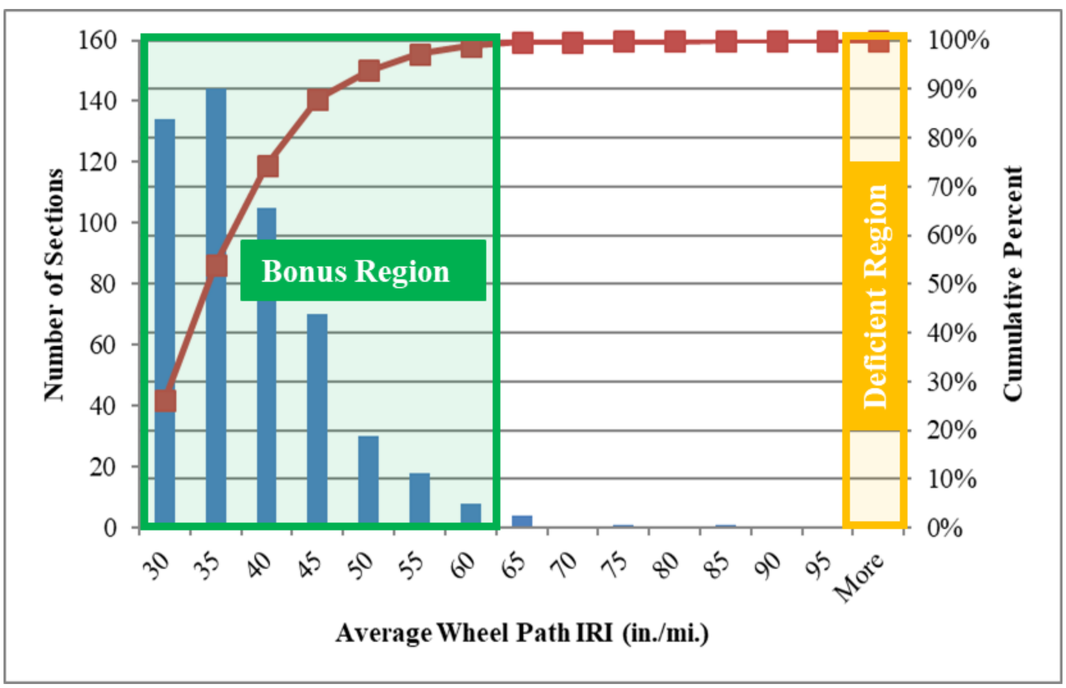

Figure 9. Average Wheel Path IRI for Multi-lift HMA (Group 7).

Figure 10 shows the distribution of average wheel path IRI values for 318 CRCP sections (from seven projects). Less than 5 percent of CRCP sections had an average IRI of less than 60 in./mi., while over 10 percent had an average IRI greater than 125 in./mi. Approximately 30 percent of CRCP sections are considered IRI deficient with IRI values greater than 95 in./mi. The average CRCP wheel path IRI is almost 40 in./mi. rougher than any of the flexible pavements except for the outside lane of a C&G section. However, the IRI of the inside wheel path in the outside lane of a C&G section is also almost 40 in./mi smoother than average CRCP sections.

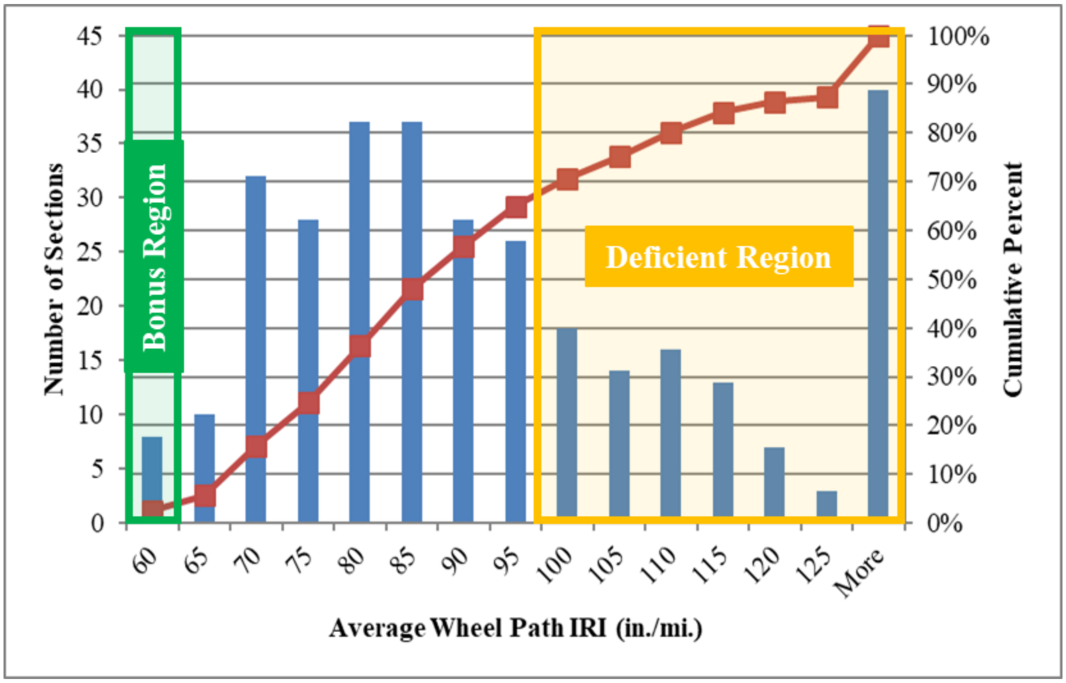

Figure 10. Average Wheel Path IRI for CRCP (Group 8).

Appendix B: Post-construction Left and Right Wheel Path IRI Values includes post-construction IRI histograms for each wheel path and construction type.

PRE- AND POST-CONSTRUCTION CHANGES IN IRI

TxDOT has a population of paving projects performed each year that consists of several subpopulations. The research team sought to adequately sample each subpopulation to accurately describe final ride quality expectations for each paving type. CRCP projects were not included in this analysis because of the assumption that CRCP projects were performed as part of new construction and preexisting conditions were not relevant.

In order to determine an adequate number of sections required for sampling, the research team reviewed 84 paving projects. Using the length of the project from the title sheet and the number of lanes from the typical section, the number of lane miles was calculated, and the number of 0.1-mi. sections was estimated. The 84 projects included 575.192 centerline miles of paving that totaled 1,633.713 lane miles. With approximately 350 paving projects let every year, the

84 randomly selected projects represent 24 percent of an annual paving portfolio. Expanding the 1,633.713 lane miles from 24 percent of the portfolio to 100 percent indicates that approximately 6,807.14 lane miles of TxDOT pavements are annually included in a paving project.

Assuming 70,000 0.1-mi. sections are annually included in a paving project, the necessary sample size was calculated using the following equation:

$$Sample\_size = \frac{\frac{z^2 \times P \times (1-P)}{e^2}}{1 + \frac{z^2 \times P \times (1-P)}{e^2 \times N}}$$

Where:

- $z\_score = 1.96$ (for the 95 percent confidence interval).
- $N = 70,000\,sec\,tions$ (N is the total number of sections desired to generalize the result of paired sections to them).
- $e = 3$ percent (e is the margin of error, which in this process is assumed to be 3 percent).
- $P = 50$ percent (P is the standard deviation in percent; it reflects what the user believes the likely sample proportion is; if unsure, this can remain at 50 percent).

The calculation resulted in the need for 1,052 sections to adequately describe changes in IRI between preconstruction and post-construction conditions at the statewide level. TxDOT provided preconstruction IRI information on 27 paving projects. The research team matched the preconstruction data with the post-construction data as closely as possible. The TxDOT data originally contained 444.13 lane miles. Post-construction data were available on 286.25 lane miles, of which 223.98 lane miles were matched using a matching algorithm. Using the matched sections, 2,230 sections were available for preconstruction and post-construction analysis, more than double the amount required to accurately describe the change in IRI from a statewide perspective.

With enough data available to describe the macroscopic nature of the change in IRI, it was important to determine if the subpopulations of each paving type were adequately sampled. To do this, a sample from each subpopulation was taken to develop an initial distribution. After developing the initial distribution, researchers resampled the subpopulation and added the new sections to the initial distribution. F- and t-tests were used to determine if the different samples could be considered from the same subpopulation. It was known that the samples were from the same population because the scope of work was already known; therefore, regardless of the F- and t-test results, the samples were included, and a new distribution was calculated. Due to the inability to completely rely on the F- and t-tests to determine when adding sections to the subpopulation should stop, the team evaluated the first-order statistics to determine a stopping point. Specifically, the average IRI value was monitored to cease including more sections once the change in average IRI created by adding sections did not exceed 6 in./mi. The stopping threshold of 6 in./mi. was used because that is the referee threshold established in Item 585. Adequately sampling the subpopulation gave the results in Table 6.

Table 6. Summary of Pre- and Post-construction Comparison.

Construction Type	Mill & Fill Outside Lane of C&G			Mill & Fill Inside Lane of C&G			Scarify & Reshape with Overlay			Overlay > 1.5 in.			Mill & Overlay > 1.5 in.			Overlay < 1.5 in.			Multiple HMA Lifts		
No. of Sections	88			89			62			983			233			195			381		
	Pre-	Post-	Δ IRI	Pre-	Post-	Δ IRI	Pre-	Post-	Δ IRI	Pre-	Post-	Δ IRI	Pre-	Post-	Δ IRI	Pre-	Post-	Δ IRI	Pre-	Post-	Δ IRI
Mean	146.7	78.3	-57.7	145.3	56.9	-88.4	160.5	61.9	-98.6	88.3	44.4	-43.9	102.6	51.3	-51.3	83.8	55.6	-28.2	70.0	36.0	-34.0
Median	141.0	74.5	-52.8	139.3	54.0	-83.8	170.8	63.0	-106.2	84.5	43.9	-40.5	90.5	49.2	-43.3	72.0	54.8	-17.0	79.0	28.9	-49.7
Std. Deviation	31.6	16.4	31.0	32.4	13.9	37.6	44.5	12.8	52.4	29.3	10.3	27.8	30.1	12.6	28.8	37.3	11.0	37.1	25.1	8.5	27.8
Max	227.0	116.9	19.4	227.0	106.9	20.4	274.0	88.3	9.3	213.0	104.4	22.1	217.0	138.4	-3.6	217.5	104.9	32.9	174.0	85.3	53.8
Min	90.5	50.6	-126.5	86.5	37.7	-188.5	64.5	35.6	-237.3	34.0	25.3	-184.0	65.0	31.4	-174.8	41.5	31.9	-181.7	28.0	22.3	-144.7

Table 6 shows that scarify and reshape with overlay projects have the roughest preconstruction condition and thus have the largest IRI improvement. This finding is not surprising because most of these types of projects are located on rural facilities that have been in service for many years with a relatively thin pavement section. Interestingly, multiple-lift HMA projects had the smoothest initial condition, followed by overly projects with a mat thickness of less than 1.5 in.

Table 6 is visualized in the following figures. Figure 11 has the smoothed cumulative distribution curve for each construction type based on group number. Scarify and reshape with overlay projects (Group 3) have the highest initial IRI values, followed by mill and fill projects in the outside lane (Group 1) and inside lane (Group 2), respectively. Figure 11 shows that these three types of projects have the roughest preconstruction ride by a wide margin (i.e., 50 in./mi. on average) before the cumulative curve for mill and overlay projects occurs (Group 5).

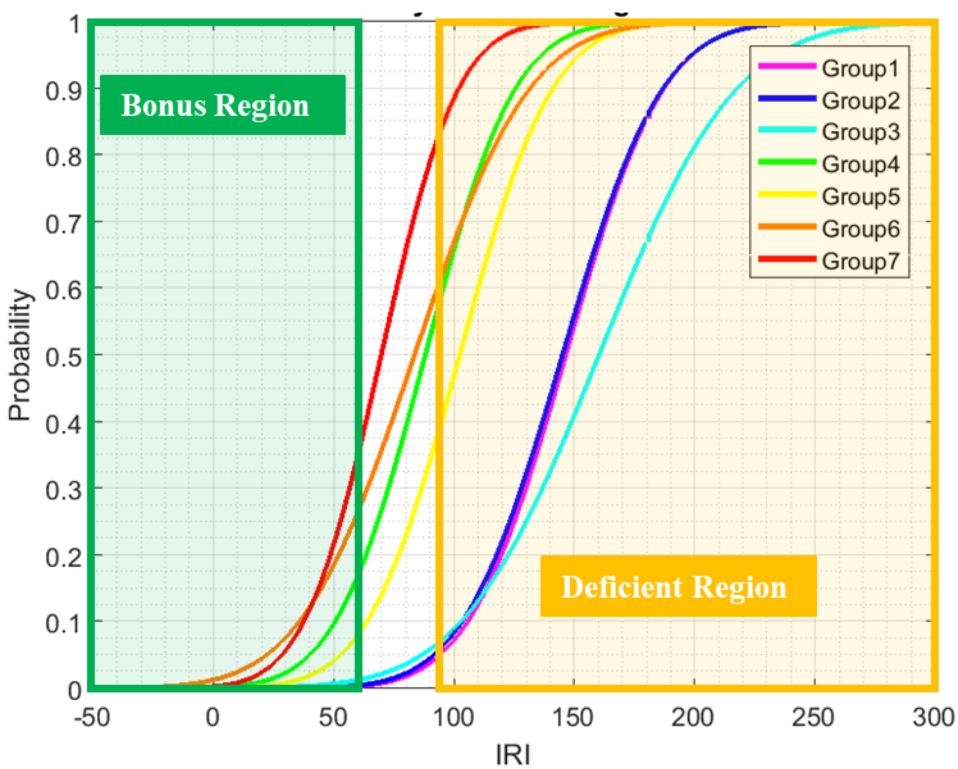

Figure 11. Cumulative Distribution Plot for Average Preconstruction IRI.

Figure 12 has the smoothed versions of the cumulative distribution curves for post-construction IRI shown in Figure 3 through Figure 9. Figure 12 shows that the outside lane of a mill and fill project (Group 1) has the roughest post-construction ride quality, followed by scarify and reshape with overlay projects (Group 3). Moving left across Figure 12 shows curves with steep slopes through the middle of the distribution. These steep slopes are indicative of small standard deviations, indicating that the final riding surface is much more uniform than the preconstruction riding surface.

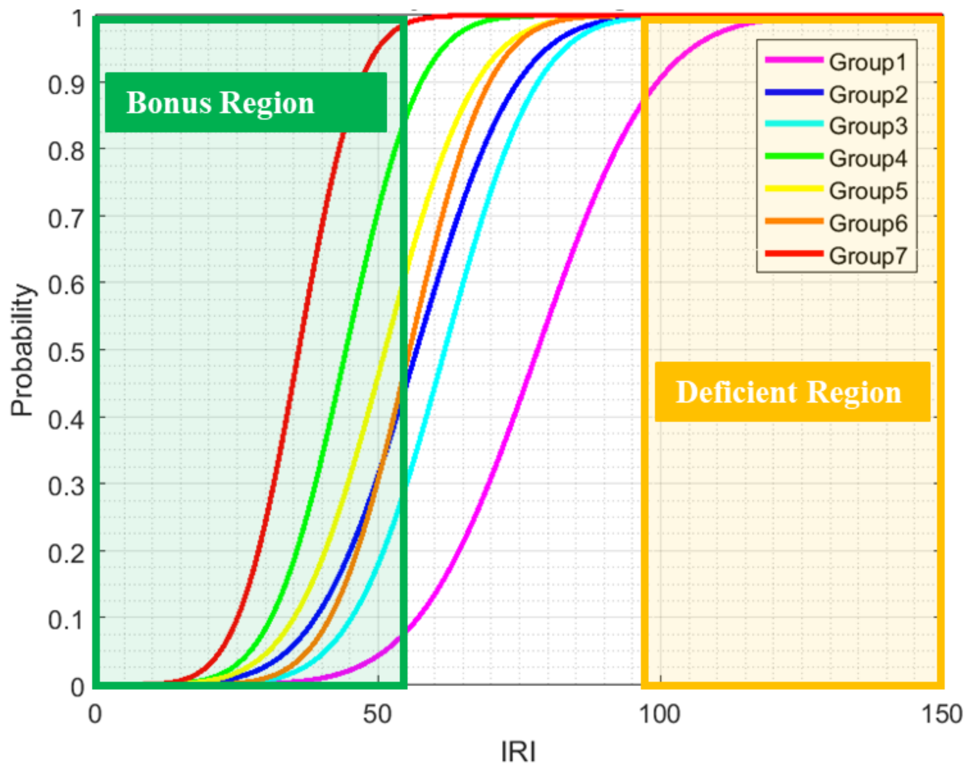

Figure 12. Cumulative Distribution Plot for Average Post-construction IRI.

Figure 13 shows that construction types with the highest preconstruction IRI also have the largest change in IRI. The change in IRI for single-lift overlay projects with a mat thickness greater than or equal to 1.5 in. (Group 4) and mill and overlay projects with a mat thickness greater than or equal to 1.5 in. (Group 5) parallel each other. From Figure 12 and Table 6, Group 5 experiences a larger ride quality improvement by approximately 7 in./mi. However, also from Figure 12 and Table 6, Group 4 has a smoother final riding surface of approximately 7 in./mi. Therefore, mill and overlay projects typically have a rougher preconstruction condition by approximately 14 in./mi. This finding is somewhat expected because the milling operation is often used to help reestablish roadway shape before the overlay. Another interesting note from Figure 12 and Table 6 is that the median preconstruction values for overlays (Group 4), mill and overlays (Group 5), and thin overlays (Group 6) are below the 95 in./mi. deficient threshold. As expected, thin overlays (Group 6) have the smoothest preconstruction condition with a median value of 72 in./mi. and approximately 27 percent of sections in the bonus region but have the smallest change in smoothness.

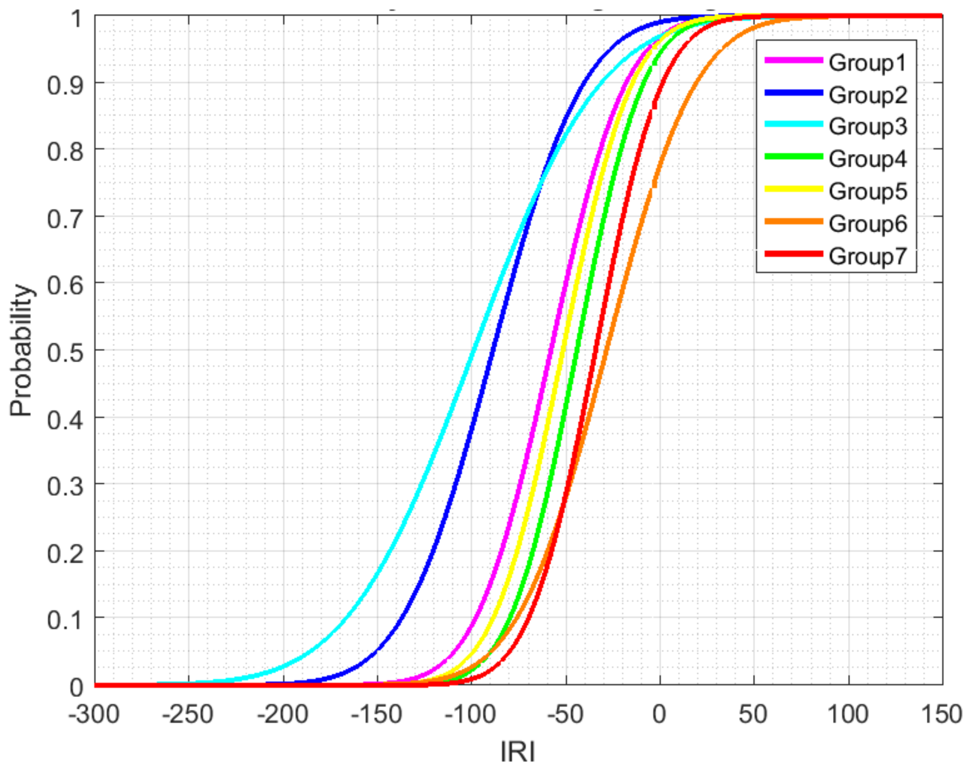

Figure 13. Cumulative Distribution Plot for Change in IRI.

SUMMARY OF RIDE QUALITY IMPROVEMENT EXPECTATIONS

A review of hundreds of typical sections from paving projects resulted in the consolidation of paving work types into eight typical construction scopes. TxDOT engineers typically select one of these eight scopes to address certain pre-existing conditions. This study assumes that engineers will continue to select paving treatments in the same way. This assumption allowed the research team to provide data-driven expectations for post-construction ride quality for the eight different construction scopes. Table 5 summarizes these expectations. The following list ranks the post construction ride smoothness from smoothest scope to roughest scope:

1. Multiple lifts of HMA greater than or equal to 1.5 in. (Group 7).
2. Overlay greater than or equal to 1.5 in. (Group 4).
3. Mill and overlay with HMA greater than or equal to 1.5 in. (Group 5).
4. HMA overlay less than 1.5 in. (Group 6).
5. Scarify and reshape base with overlay greater than or equal to 1.5 in. (Group 3).
6. Mill and fill not constrained by gutter (Group 2).
7. Mill and fill in outside lane of C&G (Group 1).
8. CRCP (Group 8).

The following section discusses a new guidance document based on construction scope and post-construction expectations.

DEVELOP A DECISION FRAMEWORK FOR PAY SCHEDULE SELECTION

TxDOT's Construction Division formalized the current guidance document for Item 585: Ride Quality for Pavement Surfaces in August 2004. Table 1 shows the current guidance document, which separates construction into four categories: new construction, major rehabilitation, overlay, and minor rehabilitation. The document further separates work types by thickness and/or opportunities for smoothness improvement. Other measures were included by considering the number of lanes and posted speed limit. The existing guidance document did not have the luxury of using vast amounts of post-construction data to inform expectations.

With data readily available, TxDOT engineers can have an expectation of post-construction quality. The guidance document developed through this research is a simple table that only considers construction scope. The researchers do not imply that other roadway characteristics are not important, simply that the data used to create the new guidance document provide an understanding of the probabilistic distribution of post-construction smoothness based on construction scope. Paving contractors seem to deploy the same techniques for the same type of scope, resulting in similar post-construction smoothness regardless of roadway attributes such as speed limit, highway classification, and number of lanes. This was expected because it would require more work on the contractor to make modifications simply because the roadway attributes changed. Nonetheless, when the data fell within a marginal range, researchers used 10,000 vehicles per day (vpd) average annual daily traffic (AADT) as a dividing value. The new guidance document also provides regression equations when preconstruction data are used to determine the expectations for post-construction smoothness.

Flexible pavement construction was categorized into one of the following seven typical HMA surfaces:

1. Mill and fill in outside lane of C&G.
2. Mill and fill when the mat is not constrained to a gutter pan.
3. Scarify and reshape base with an overlay equal to or greater than 1.5 in.
4. HMA overlay with a depth greater than or equal to 1.5 in.
5. Mill and overlay with HMA greater than or equal to 1.5 in.
6. HMA overlay with a depth less than 1.5 in.
7. Multiple HMA lifts with a depth greater than or equal to 1.5 in.

Guidance was developed using the existing Item 585 bonus/penalty structure and statistics from the post-construction distributions of each HMA surface. The benchmarks within the existing bonus/penalty structure used were:

- Post-construction sections with an IRI greater than 95 in./mi. are considered deficient.

- For Pay Schedule 2, the penalty begins at 76 in./mi., and the bonus begins at 59 in./mi. The 60 in./mi. to 75 in./mi. range represents a $0 pay range.
- For Pay Schedule 1, the penalty begins at 66 in./mi., and the bonus begins at 59 in./mi. The 60 in./mi. to 65 in./mi. range represents a $0 pay range.

The large number of sections used in the analysis helped create post-construction quartiles used for guidance. Table 7 shows the 25th, 50th, and 75th percentiles for post-construction IRI for each of the seven flexible pavement construction types. The following conclusions and logic were used to further build a guidance table:

- For mill and inlay adjacent to C&G, the 75th percentile was below the deficient section threshold of 95 in./mi. but was within the penalty range for Pay Schedules 1 and 2. This logic was used as a benchmark to remove Pay Schedules 1 and 2 as options for this work type. Furthermore, the 50th percentile was in the $0 pay band for Pay Schedule 2 and penalty for Pay Schedule 1. No bonus for any pay schedule was achieved at any of the percentiles, implying only a small number of sections for this work type existed in the bonus range. For this reason, Pay Schedule 3 is recommended for this work type.
- For mill and inlay, the 75th percentile post-construction IRI was within the $0 band for Pay Schedule 2 but penalty for Pay Schedule 1; therefore, Pay Schedule 1 was removed from consideration. Both the 50th and 25th percentiles were within the bonus range for Pay Schedules 2 and 3. Pay Schedule 2 or 3 is recommended for this work type.
- For scarify and reshape with an overlay, the 75th percentile was within the penalty for Pay Schedule 1, eliminating it from consideration. Both the 50th and 75th percentiles exist within the $0 pay band for Pay Schedule 2, implying that a bonus was achieved on fewer than half the sections. While a penalty for this type of work does not appear to be a major concern, the inability to achieve a bonus at either the 50th or 75th percentile led to the recommendation to use Pay Schedule 3 for this work type.
- For single-lift HMA overlays with a mat thickness greater than or equal to 1.5 in., percentiles were within the bonus range, leading to the recommendation to use Pay Schedule 1 for this work type.
- For unconfined milling with a single-lift overlay greater than or equal to 1.5 in., the 75th percentile was at the lower limit of the $0 band for both Pay Schedules 1 and 2. The 25th and 50th percentiles were both within the bonus range, so Pay Schedule 1 or 2 is recommended for this work type.
- For thin-lift HMA overlays with a mat thickness less than 1.5 in., the 75th percentile was at the lower limit of the $0 band for both Pay Schedules 1 and 2. The 25th and 50th percentiles were both within the bonus range, so Pay Schedule 1 or 2 is recommended for this work type.

- For multiple-lift HMA construction where each mat is greater than or equal to 1.5 in., all percentiles were within the bonus structure, so Pay Schedule 1 is recommended for this work type.

Table 7. 25th, 50th, and 75th Percentile IRI Values for Flexible Pavement Construction.

Work Type	Statewide Data Distribution 25th Percentile	Statewide Data Distribution 50th Percentile	Statewide Data Distribution 75th Percentile
Mill & fill in outside lane of C&G	67	70	90
Mill & fill not constrained by gutter	48	55	67
Scarify & reshape base with overlay ≥ 1.5 in.	53	62	71
Overlay ≥ 1.5 in.	37	45	52
Mill & overlay with HMA ≥ 1.5 in.	43	52	60
Overlay < 1.5 in.	48	55	63
Multiple lifts of HMA ≥ 1.5 in.	30	36	42

This logic can be summarized by the following:

- If the 75th percentile and 50th percentile are within the $0 pay bands or penalty, Pay Schedule 3 is recommended.
- If the 75th percentile is within the Pay Schedule 2 $0 pay band and penalty for Pay Schedule 1, and the 50th percentile is within the bonus range, Pay Schedule 2 or 3 is recommended.
- If the 75th percentile is within the $0 pay band for both Pay Schedules 1 and 2 and the 50th percentile is within the bonus range, Pay Schedule 1 or 2 is recommended.
- If both the 75th and 50th percentiles are within the bonus range, Pay Schedule 1 is recommended.

Table 8 summarizes this data-driven guidance.

Table 8. Generic Guidance Table.

Work Type	Statewide Data Distribution 25th Percentile	Statewide Data Distribution 50th Percentile	Statewide Data Distribution 75th Percentile	Recommended Pay Schedule
Mill & fill in outside lane of C&G	67	70	90	3
Mill & fill not constrained by gutter	48	55	67	2 or 3
Scarify & reshape base with overlay ≥ 1.5 in.	53	62	71	3
Overlay ≥ 1.5 in.	37	45	52	1
Mill & overlay with HMA ≥ 1.5 in.	43	52	60	1 or 2
Overlay < 1.5 in.	48	55	63	1 or 2
Multiple lifts of HMA ≥ 1.5 in.	30	36	42	1

Table 8 functions as a simplified guidance table that decision makers can use when they have no data on the preconstruction ride quality and want to decide based on average expectations. The data-driven approach leads to the selection of Pay Schedules 1 and 2 much more often than suggested by the current guidance document and much more frequently than currently practiced across the state. This comes from the fact that pavements are placed smoother than 15 years ago, and data now exist to quantify the typical smoothness. For TxDOT, this means contractors can meet the bonus requirements in Pay Schedules 1 and 2 on projects that have typically selected Pay Schedule 3. Because the project can currently achieve those levels of smoothness without making construction adjustments, selecting Pay Schedule 1 or 2 in lieu of Pay Schedule 3 would lead to TxDOT paying more bonuses but not necessarily improving smoothness. For this reason, the research also explored modifying the bonus/penalty structure and investigated how tighter specifications might improve statewide smoothness. The research team believes that implementing the new guidance document without modifying the bonus/penalty structure would only marginally improve statewide smoothness, while TxDOT would pay much more in bonuses (i.e., over $1 million per year, a 12.5 percent increase). Therefore, the guidance document as presented should be used to inform district decision makers on what to expect from the contractor but should only be implemented as a pay schedule selection document in conjunction with a bonus/penalty modification of Item 585.

Before discussing modifications to the bonus/penalty structure, the guidance document is further developed to account for the presence of preconstruction data. In addition to addressing preconstruction data, construction scopes with an “or” option for pay schedule selection were reconciled. The existing guidance document considers several roadway attributes for pay schedule selection. Because the research team pursued a data-driven approach, arbitrary roadway attributes were not used; rather, AADT and statistics associated with the AADT for projects were used. The research team found that Pay Schedule 2 was selected on 21 percent of projects with AADT less than 10,000 vpd, while it was selected 45 percent of the time on projects with more than 10,000 vpd. Therefore, the 10,000 vpd traffic volume was used to separate the “or” option shown in Table 8.

The new guidance table initially considered three options:

- Select a pay schedule with no available data about the existing smoothness (similar to Table 8).
- Select a pay schedule with network-level data.
- Select a pay schedule with project-level data.

As previously discussed, TxDOT provided network-level preconstruction data on 27 projects. Network-level data are most often provided by TxDOT’s Maintenance Division on 0.1-mi increments using reference markers for location purposes. Using network-level data, the guidance document provides a regression equation to estimate the post-construction smoothness.

Users should remember that network-level data are only available on one lane. Therefore, predicting the post-construction smoothness only applies specifically to the lane used during data collection. Also, the user should understand that the network-level data do not coincide with the exact begin and end construction limits of a project. Nonetheless, the local decision makers' knowledge of the actual conditions should allow them to know if the results from one lane can be extrapolated to the project. Using the guidance for this method involves taking the network-level data and predicting the change in IRI for each section using the regression equation. After prediction of the change in IRI, the post-construction IRI for each section should be calculated. Using the post-construction IRI values, the user should calculate the 75th percentile IRI value and use it and the guidance table to select a pay schedule. These calculations can be easily performed in an Excel® spreadsheet.

Table 9 provides the final recommended guidance document in a simplified table format. It answers the question of how to select an existing pay schedule when no preconstruction data are available. The table also provides regression equations to predict the change in IRI given a preexisting IRI value. By using this change, a post-construction IRI value can be calculated, and depending upon the distribution of the predicted post-construction values, a pay schedule can be selected. The regression equations should be used for both network-level and project-level data. Project-level data were collected on a smaller sample of projects, but the sample size and construction scope were too limited to develop different regression equations when project-level data are available.

Table 9 also provides guidance for CRCP. The statistical analysis for CRCP showed that sections in the 75th percentile and greater were ride deficient. However, because CRCP construction corresponds to new construction, the guidance document recommends Pay Schedule 3 for roadways with more than 10,000 vpd. While rare, concrete pavements on roadways with traffic volume less than 10,000 vpd should consider Test Type A to evaluate smoothness. No data were available for jointed concrete pavements, so the guidance for CRCP was used as the recommendation.

Table 9. Recommended Guidance Table.

Select Pay Schedule based on predominant work type and no existing condition data

Work Type	Statewide Data Distribution: 25th Percentile	Statewide Data Distribution: 50th Percentile	Statewide Data Distribution: 75th Percentile	Pay Schedule when AADT < 10,000 vpd	Pay Schedule when AADT ≥ 10,000 vpd
Mill & fill in outside lane of C&G	67	70	90	3	3
Mill & fill not constrained by gutter	48	55	67	3	2
Scarify & reshape base with overlay ≥ 1.5 in.	53	62	71	3	3
Overlay ≥ 1.5 in.	37	45	52	1	1
Mill & overlay with HMA ≥ 1.5 in.	43	52	60	2	1
Overlay < 1.5 in.	48	55	63	2	1
Multiple lifts of HMA ≥ 1.5 in.	30	36	42	1	1
CRCP	75	93	105	Test Type A	3
JCP	NA	NA	NA	Test Type A	3

Calculate Pay Schedule using network-level data and the predicted 75th percentile post-construction IRI value

Work Type	Regression Equation	Predicted Post-Construction IRI	Pay Schedule 1	Pay Schedule 2	Pay Schedule 3	Test Type A
Mill & fill in outside lane of C&G	Predicted Change IRI = -0.84*Preconstruction + 65.90	Network-Level Data + Predicted Change	75th Percentile < 60	60 ≤ 75th Percentile < 75	75 ≤ 75th Percentile < 95	75th Percentile ≥ 95
Mill & fill not constrained by gutter	Predicted Change IRI = -1.08*Preconstruction + 68.64					
Scarify & reshape base with overlay ≥ 1.5 in.	Predicted Change IRI = -1.15*Preconstruction + 86.66					
Overlay ≥ 1.5 in.	Predicted Change IRI = -0.89*Preconstruction + 34.42					
Mill & overlay with HMA ≥ 1.5 in.	Predicted Change IRI = -0.87*Preconstruction + 38.03					
Overlay < 1.5 in.	Predicted Change IRI = -0.95*Preconstruction + 51.50					
Multiple lifts of HMA ≥ 1.5 in.	Predicted Change IRI = -1.05*Preconstruction + 39.77					
CRCP			Schedule 3 or Test Type A on roadways with less than 10,000 vpd			
JCP						

Note: For more conservative values, add 3 in./mi. to the 75th percentile value. For very conservative selection, add 6 in./mi. to the 75th percentile value.

The R^2 values for the regression equations for each of the flexible pavement projects are listed in Table 10.

Table 10. R^2 for Work Group Regression Equations

Work Type	R^2 for Regression Equation
Mill & fill in outside lane of C&G	0.74
Mill & fill not constrained by gutter	0.87
Scarify & reshape base with overlay ≥ 1.5 in.	0.96
Overlay ≥ 1.5 in.	0.87
Mill & overlay with HMA ≥ 1.5 in.	0.83
Overlay < 1.5 in.	0.91
Multiple lifts of HMA ≥ 1.5 in.	0.91

Appendix C: Regression Equation Plots for Post-construction Prediction provides charts displaying the post-construction data for all project types and the prediction curves.

Assuming TxDOT engineers continue to select construction types as they do now, users of the new guidance table with preconstruction data can have high confidence in the predictions for most construction types. The mill and inlay predictions adjacent to the C&G have the lowest R^2. This result is not surprising because of the impact the fixed point of the gutter pan has on the final mat smoothness, particularly the outside wheel path. The number of driveways, age of the C&G, deterioration of the gutter during milling, and other variables impact the prediction ability of the equation. While this is a limitation, the recommended pay schedule for this construction scope is Pay Schedule 3 under the existing specification structure.

Predicting the post-construction IRI with preconstruction data also allows the district to identify potentially deficient sections after construction. Deficient sections are defined as sections with average IRI greater than 95 in./mi. When these sections are predicted, districts can alert the contractor, select an additional construction technique such as level-up, or simply prepare to waive the IRI in that section.

The research team also sought to use project-level data to identify trends in the reduction of localized roughness or to determine the impact of various construction techniques on localized roughness. The dataset included preconstruction and post-construction measurements on each lane of seven projects. These data were inconclusive with respect to identifying changes in localized roughness. One of the reasons that the data were inconclusive was the nature of construction. When analyzing the data, researchers discovered that while some preconstruction bumps or dips were eliminated during construction, new bumps or dips were present that did not exist prior to construction. The paving operation, including the staging of trucks and the location of transverse joints likely introduced new bumps and dips. If a thorough review of construction impact on preexisting localized roughness is desired, the research team recommends identifying a statistically significant number of projects from each construction group (Groups 1, 2, 4, 5, and 6) and perform a detailed analysis of localized roughness. This analysis should include not only preconstruction profile measurements, but visual confirmation of the localized roughness, on-site presence during construction to ensure contiguous paving over the localized roughness, and post-construction ride quality analysis. The on-site presence during construction and the post-construction analysis should also attempt to determine why new bumps and dips are introduced during construction. This scope of work serves as additional research needed rather than implementation of the guidance document.

EVALUATE BONUS/PENALTY MODIFICATIONS

In order to evaluate changes to the bonus/penalty structure, it was important to quantify the amount of bonus (or penalty) TxDOT pays annually. The average post-construction IRI on flexible paving projects was between 45 and 50 in./mi.; therefore, TxDOT pays between $200 and $300 per 0.1-mile section on Pay Schedule 1 and 2 projects and pays half that on Pay Schedule 3 projects. Over 80 percent of post-construction flexible pavement sections are in the bonus category.

CURRENT ESTIMATED BONUS/PENALTY PAID BY TXDOT

TxDOT annually lets between 300 and 400 paving projects, of which it enforces Item 585 on approximately 300. A review of 94 paving projects found that the median number of 0.1-mile sections within a paving project was 149, indicating the median paving project length is 14.9 lane miles. Using the preceding data, it was calculated that TxDOT annually enforces Item 585 on approximately 44,700 sections.

The statewide distribution for pay schedule selection in FY 2018 is listed below:

- Pay Schedule 3 for 43 percent of projects.
- Pay Schedule 2 for 35 percent of projects.
- Pay Schedule 1 for 22 percent of projects.

Using this distribution and post-construction ride quality data for 94 projects (6,442 sections), the amount of bonus annually paid for ride quality was estimated at between $7.8 million and $8.0 million. The percentage of sections requiring corrective work (i.e., IRI greater than 95 in./mi) was estimated at 2 percent.

ESTIMATED BONUS/PENALTY USING EXISTING SPECIFICATION AND NEW GUIDANCE

Under the draft guidance document, the distribution of pay schedule selection would change, influencing the estimate of statewide payout. Using the new guidance, TxDOT districts would select Pay Schedules 1 and 2 more frequently. The following is the anticipated pay schedule distribution using the new guidance document:

- Pay Schedule 3 for 12 percent of projects.
- Pay Schedule 2 for 22 percent of projects.
- Pay Schedule 1 for 66 percent of projects.

Using Pay Schedule 1 more frequently offers contractors the opportunity to accrue more bonus, and the analyses have shown that the bonus is not only achievable but the norm. The estimated statewide payout using the new guidance and the existing specification structure would total $9.1 million, approximately a 12.5 percent increase.

RECOMMENDED PAY STRUCTURE CHANGES

Researchers recommend using the proposed guidance document for informational purposes to establish expectations for post-construction ride quality if TxDOT does not want to simultaneously pursue changes to the pay structure in the Standard Specifications. The reason to use the new guidance for informational purposes rather than the selection of pay schedules is to prevent TxDOT from paying out more bonuses without seeing substantial improvement to statewide ride quality. Ideally, TxDOT begins to implement the new guidance document to expand the ride quality knowledge across TxDOT while working to revise the pay structure in the specification to represent a data-driven pay structure for each work group. A more thorough discussion of the implementation plan is discussed later in this report.

The use of individual pay structures for work types is not unprecedented within TxDOT because the Special Specification (SS 3012) associated with NGCS has a standalone pay structure for that specific work type. The modifications recommended for the pay structure within Item 585 would follow this precedent and provide TxDOT the opportunity to incorporate the pay structure for SS 3012 into Item 585.

While developing a new pay structure, researchers sought to create a structure that was close to revenue neutral (i.e., TxDOT would continue to annually pay approximately $8 million in ride quality bonus). Researchers also sought to structure the new pay structure in a way that average expected ride quality would represent the $0 pay band, currently starting at 60 in./mi. in the existing specification. The bonus or penalty amount moving away from the average increases on an even increment of $50 for each 1 in./mi. over a 10 in./mi. window beyond the $0 pay band. After this window, the amount of bonus or penalty increases more rapidly to reward smoother pavements and penalize rougher pavements. The bonus/penalty curves were established to reflect the cumulative distribution curves for each work type.

Following this logic gives a bonus/penalty structure reflective of the expectations for a construction group. For example, scarify and reshape with overlay projects (Group 3) typically occur on lower-volume rural roadways. Historically, these projects would have used Pay Schedule 3 where no penalty occurred and the bonus was limited below that of Pay Schedule 1 or 2. On the other hand, multiple-lift HMA construction (Group 7) could occur on a high-volume roadway, and Pay Schedule 1 would have been selected. If this were the case and each project had a section with an average IRI of 47 in./mi., the scarify and reshape project would have received a $130 bonus for that section. The multiple-lift HMA project would have received a $260 bonus for the same IRI value. However, the data tell us that on a scarify and reshape project, the 47-in./mi. section would have been in the smoothest 25 percent of all sections (Table 7), while it would have been in the roughest 25 percent of sections on the multiple-lift

HMA project (Table 7). The data-driven nature of the proposed bonus/penalty structure seeks to more lucratively reward the 47-in./mi. section on the scarify and reshape project while penalizing it on the multiple-lift HMA project. Essentially, the proposed changes evaluate a work type and then try to apply a pay structure to incentivize performing above expectations and disincentivize performing below expectations. This approach was selected after an iterative process of trying to create three pay schedules, similar to what currently exists, failed. The data across the different construction groups are too different to aggregate into three pay structures. Researchers recommend following the lead of SS 3012 and building pay structures for individual work groups.

Table 11 shows the proposed pay structure for each construction type. The maximum bonus and penalty values are $3,000 per section and −$3,000 per section, respectively. This is much higher than the current maximum bonus of $600 per section, and while the maximum penalty is −$3,000, it occurs as a step function at 95 in./mi. in the existing pay structure. The color system within Table 11 provides the reader with perspective on the structure. All $0-per-section bands are shaded in blue and represent the ride quality distribution near the average expectation. In actuality, the low IRI end of the $0-per-section band is the closest value to the average so that contractors are afforded the opportunity to receive a bonus when providing smoothness below the average expectation. The $0-per-section pay band extends for 10 in./mi. in the rougher direction before a penalty begins for all pay groups except concrete pavements. Beyond the $0 pay band in the bonus and penalty direction, $50-per-section increments are used for all construction types and shaded in yellow with penalty values in red. This is true for concrete pavements as well for the bonus side, while no penalty is proposed. The need for a separate pay structure for concrete pavements is discussed later in the report. Maximum bonus and penalty values are shaded in green with the penalty values in red.

Using the same example as previously used to make the case for pay structures for each construction type, this example assumes a scarify and reshape and multiple-lift HMA project with a section IRI of 47 in./mi. Under the proposed bonus and penalty structure, the 47-in./mi. section of the scarify and reshape with overlay project (Group 3) would receive a bonus of $875 compared with $130 under the old structure. This significant increase in bonus occurs because it is not common to have a section of scarify and reshape with overlay projects as smooth as 47 in./mi. The goal with this type of structure is to incentivize contractors to improve smoothness to acquire the more lucrative bonus. On the other hand, the multiple-lift HMA (Group 7) section with an IRI of 47 in./mi. would receive a penalty of −100 compared to a bonus of $260 under the existing structure. This penalty occurs because the expectation of a contractor on a multiple-lift HMA project is that high levels of smoothness should be achieved, and the bonus should only be paid when better than average construction is achieved.

Table 11. Proposed Pay Structure for Each Work Type.

Section IRI (in./mi.)	Group 1 ($/section)	Group 2 ($/section)	Group 3 ($/section)	Group 4 ($/section)	Group 5 ($/section)	Group 6 ($/section)	Group 7 ($/section)	Group 8 ($/section)
20	3000	3000	3000	3000	3000	3000	3000	3000
21	3000	3000	3000	3000	3000	3000	2575	3000
22	3000	3000	3000	3000	3000	3000	2160	3000
23	3000	3000	3000	3000	3000	3000	1745	3000
24	3000	3000	3000	3000	3000	3000	1330	3000
25	3000	3000	3000	3000	3000	3000	915	3000
26	3000	3000	3000	2750	3000	3000	500	3000
27	3000	3000	3000	2500	3000	3000	450	3000
28	3000	3000	3000	2250	3000	3000	400	3000
29	3000	3000	3000	2000	3000	3000	350	3000
30	3000	3000	3000	1750	3000	3000	300	3000
31	3000	2750	2875	1500	2750	3000	250	3000
32	3000	2500	2750	1250	2500	3000	200	3000
33	3000	2250	2625	1000	2250	3000	150	3000
34	3000	2000	2500	750	2000	3000	100	3000
35	3000	1750	2375	500	1750	3000	50	3000
36	2875	1500	2250	450	1500	2750	0	3000
37	2750	1250	2125	400	1250	2500	0	3000
38	2625	1000	2000	350	1000	2250	0	3000
39	2500	750	1875	300	750	2000	0	3000
40	2375	500	1750	250	500	1750	0	3000
41	2250	450	1625	200	450	1500	0	3000
42	2125	400	1500	150	400	1250	0	3000
43	2000	350	1375	100	350	1000	0	3000
44	1875	300	1250	50	300	750	0	3000
45	1750	250	1125	0	250	500	0	3000
46	1625	200	1000	0	200	450	-50	3000
47	1500	150	875	0	150	400	-100	3000
48	1375	100	750	0	100	350	-150	3000
49	1250	50	625	0	50	300	-200	3000
50	1125	0	500	0	0	250	-250	3000
51	1000	0	450	0	0	200	-300	3000
52	875	0	400	0	0	150	-350	3000
53	750	0	350	0	0	100	-400	3000
54	625	0	300	0	0	50	-450	3000
55	500	0	250	-50	0	0	-500	3000
56	450	0	200	-100	0	0	-600	2810
57	400	0	150	-150	0	0	-700	2645
58	350	0	100	-200	0	0	-800	2480
59	300	0	50	-250	0	0	-900	2315
60	250	-50	0	-300	0	0	-1000	2150

Table 11. Proposed Pay Structure for Each Work Type (Continued).

Section IRI (in./mi.)	Group 1 ($/section)	Group 2 ($/section)	Group 3 ($/section)	Group 4 ($/section)	Group 5 ($/section)	Group 6 ($/section)	Group 7 ($/section)	Group 8 ($/section)
60	250	-50	0	-300	0	0	-1000	2150
61	200	-100	0	-350	-50	0	-1100	1985
62	150	-150	0	-400	-100	0	-1200	1820
63	100	-200	0	-450	-150	0	-1300	1655
64	50	-250	0	-500	-200	0	-1400	1490
65	0	-300	0	-660	-250	0	-1500	1325
66	0	-350	0	-820	-300	-50	-1600	1160
67	0	-400	0	-980	-350	-100	-1700	995
68	0	-450	0	-1140	-400	-150	-1800	830
69	0	-500	0	-1300	-450	-200	-1900	665
70	0	-570	-50	-1460	-500	-250	-2000	500
71	0	-640	-100	-1620	-750	-300	-2100	450
72	0	-710	-150	-1780	-1000	-350	-2200	400
73	0	-780	-200	-1940	-1250	-400	-2300	350
74	0	-850	-250	-2100	-1500	-450	-2400	300
75	0	-920	-300	-2260	-1750	-500	-2500	250
76	-50	-990	-350	-2420	-2000	-600	-2600	200
77	-100	-1060	-400	-2580	-2250	-700	-2700	150
78	-150	-1130	-450	-2740	-2500	-800	-2800	100
79	-200	-1200	-500	-2900	-2750	-900	-2900	50
80	-250	-1270	-655	-3000	-3000	-1000	-3000	0
81	-300	-1340	-810	Deficient	Deficient	-1100	Deficient	0
82	-350	-1410	-965			-1200		0
83	-400	-1480	-1120			-1300		0
84	-450	-1550	-1275			-1400		0
85	-500	-1620	-1430			-1500		0
86	-625	-1690	-1585			-1600		0
87	-750	-1760	-1740			-1700		0
88	-875	-1830	-1895			-1800		0
89	-1000	-1900	-2050			-1900		0
90	-1125	-1970	-2205			-2000		0
91	-1250	-2040	-2360			-2100		0
92	-1375	-2110	-2515			-2200		0
93	-1500	-2180	-2670			-2300		0
94	-1625	-2250	-2825			-2400		0
95	-1750	-2320	-3000			-2500		0
96	-1875	-2390	Deficient			-2600		0
97	-2000	-2460				-2700		0
98	-2125	-2530				-2800		0
99	-2250	-2600				-2900		0
100	-2375	-2670				-3000		0
101	-2500	-2740				Deficient		0
102	-2625	-2810						0
103	-2750	-2880						0
104	-2875	-2950						0
105	-3000	-3000						0
>105	Deficient	Deficient						Deficient

An IRI value for deficient sections was established for each work group as well. Currently, deficient sections are defined as sections above 95 in./mi. In order for the data to establish the deficient section, researchers identified the 97.5 percentile and 99 percentile IRI value on the cumulative distribution curves. Using this window, researchers found the nearest 10th or 50th increment to assign as the maximum penalty point. For Groups 1 and 2, this value was raised from the existing 95 in./mi. to 105 in./mi. Raising this value addresses the inherent limitations on trying to construct smooth pavements through mill and fill construction in C&G sections (i.e., a constrained edge). Group 6 (i.e., thin-lift overlays) was the only other HMA surface type where researchers recommend raising the deficient threshold. For Group 6, researchers recommend raising the deficient threshold to 100 in./mi. Raising the threshold for Group 6 helps protect the contractor from an overly punitive structure when there is little opportunity to improve ride quality. As discussed previously, Group 6 projects have the smoothest preconstruction IRI values, so raising the deficient threshold acknowledges that if a very rough preconstruction section is encountered prior to construction, it is not normal and the contractor should be provided some leeway to make reasonable improvements and avoid having the section classified as deficient.

Other data in other work groups suggested lowering the deficient threshold. For scarify and reshape with an overlay projects (Group 3), the data suggested keeping 95 in./mi. as the deficient threshold, but on Groups 4, 5, and 7, the values should be lowered to 80 in./mi. Within the existing pay structure, when Pay Schedule 1 or 2 is specified and a deficient section is measured, contractors can repair the section or pay a $3,000 penalty. An analysis was not performed on the appropriate deficient section compensation if corrective work is not performed. However, the researchers recommend making it equal across all construction types. With a proposed maximum penalty of $3,000, the deficient compensation should be higher with such magnitude to strongly encourage avoiding it. Assuming a 12-ft.-wide lane over a 0.1-mi. section with 2 in. of HMA required to completely repave the deficient section, approximately 750 tons are required. Assuming an in-place HMA cost of $90/ton, the value of that construction is almost $7,000. Therefore, a reasonable deficient section penalty in lieu of corrective work should be selected between $6,000 and $7,000 per section. Based on the data, the number of sections for which this will apply is approximately 2 percent on HMA sections and 30 percent on concrete sections.

The maximum bonus threshold shown in Table 11was determined similarly to the determination used to identify the maximum penalty. The data were evaluated to determine the highest performing sections with regards to smoothness (i.e., the 97.5 percentile to 99 percentile). Using these values to establish the maximum bonus ensures that if a contractor achieves maximum bonus, it occurs not simply because the pavement is smooth, but because the smoothness significantly exceeds expectations. provides graphical representations for the proposed bonus/penalty structure for each construction type.

Intuitively, one might wonder if the proposed structure remains revenue neutral. As previously discussed, TxDOT pays approximately $8 million annually in ride quality bonuses, which equates to approximately a bonus of $180 per section. Using the existing dataset and selecting the proposed pay schedule based on work type, the average bonus per section is shown in Table 12.

Table 12. Bonus Paid Per Section

Work Type	Bonus ($) Per Section
Mill & fill in outside lane of C&G	$179
Mill & fill not constrained by gutter	$174
Scarify & reshape base with overlay ≥ 1.5 in.	$211
Overlay ≥ 1.5 in.	$216
Mill & overlay with HMA ≥ 1.5 in.	$200
Overlay < 1.5 in.	$177
Multiple lifts of HMA ≥ 1.5 in.	$149
CRCP	$196

Extrapolating this payout to the estimated number of sections for each pavement type results in a revenue neutral change.

A complete shift to a pay structure of this type would look like the pay structure provided in SS 3012 for NGCS. Figure 14 is the pay adjustment schedule taken from SS 3012 and shows a tabular bonus/penalty structure using a formula between the $0 pay band and maximum bonus.

Pay Adjustment Schedule

Average IRI for each 0.10 mi. of Traffic Lane (in./mi.)	Pay Adjustment ($/0.10 mi. of Traffic Lane)
0-35	704
35.1-45	-69.703(IRI)+3143.6
45.1-50	0.00
>50	Corrective Action

Figure 14. SS 3012 Pay Adjustment Table.

Table 13 shows a similar structure for each of the construction groups that represent typical paving projects across Texas. Table 13 uses the construction group number rather than the work scope as the descriptor. Researchers believe using generic language fits better into a standard specification, and the guidance document can be used to inform TxDOT engineers which construction scope applies to each group. Furthermore, the generic nature provides TxDOT flexibility to choose the pay schedule. This flexibility is often needed to address project-specific concerns that can only be known by local personnel although researchers recommend using preconstruction data to better inform the decision. The pay structure for concrete construction is discussed in more detail later in this report, and Table 13 is revisited in the conclusions portion of the report.

Table 13. Proposed Pay Structure in Tabular Format with Formulas.

Group 1		Group 2		Group 3	
Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)	Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)	Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)
IRI < 35	3000	IRI < 30	3000	IRI < 30	3000
35 ≤ IRI < 55	-125*(IRI)+7375	30 ≤ IRI < 40	-250*(IRI)+10500	30 ≤ IRI < 50	-125*(IRI)+6750
55 ≤ IRI < 65	-50*(IRI)+3250	40 ≤ IRI < 50	-50*(IRI)+2500	50 ≤ IRI < 60	-50*(IRI)+3000
65 ≤ IRI < 76	0	50 ≤ IRI < 60	0	60 ≤ IRI < 70	0
76 ≤ IRI < 85	-50*(IRI)+3750	60 ≤ IRI < 70	-50*(IRI)+2950	70 ≤ IRI < 80	-50*(IRI)+3450
85 ≤ IRI < 105	-125*(IRI)+10125	70 ≤ IRI < 105	-70*(IRI)+4330	80 ≤ IRI < 95	-155*(IRI)+11745
105 ≤ IRI	Deficient	105 ≤ IRI	Deficient	95 ≤ IRI	Deficient

Group 4		Group 5		Group 6	
Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)	Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)	Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)
IRI < 25	3000	IRI < 30	3000	IRI < 35	3000
25 ≤ IRI < 35	-250*(IRI)+9250	30 ≤ IRI < 40	-250*(IRI)+10500	35 ≤ IRI < 45	-250*(IRI)+11750
35 ≤ IRI < 45	-50*(IRI)+2250	40 ≤ IRI < 50	-50*(IRI)+2500	45 ≤ IRI < 55	-50*(IRI)+2750
45 ≤ IRI < 55	0	50 ≤ IRI < 60	0	55 ≤ IRI < 65	0
55 ≤ IRI < 65	-50*(IRI)+2700	60 ≤ IRI < 70	-50*(IRI)+3000	65 ≤ IRI < 75	-50*(IRI)+3250
65 ≤ IRI < 80	-160*(IRI)+9740	70 ≤ IRI < 80	-250*(IRI)+17000	75 ≤ IRI < 100	-100*(IRI)+7000
80 ≤ IRI	Deficient	80 ≤ IRI	Deficient	100 ≤ IRI	Deficient

Group 7		Group 8	
Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)	Average IRI Range for 0.1-mi. section (in./mi.)	Pay Adjustment ($/0.1-mi Section)
IRI < 20	3000	IRI < 56	3000
20 ≤ IRI < 26	-145*(IRI)+11290	56 ≤ IRI < 70	-165*(IRI)+12050
26 ≤ IRI < 36	-50*(IRI)+1800	70 ≤ IRI < 80	-50*(IRI)+4000
36 ≤ IRI < 46	0	80 ≤ IRI	0
46 ≤ IRI < 56	-50*(IRI)+2250	105 ≤ IRI	Deficient
56 ≤ IRI < 80	-100*(IRI)+5000		
80 ≤ IRI	-3000		

INVESTIGATE HOW TIGHTER SPECIFICATIONS COULD IMPACT STATEWIDE SMOOTHNESS

Pay Schedule 1 projects currently represent new construction or major rehabilitations, whereas Pay Schedules 2 and 3 are selected for different types of resurfacing. For this reason, the team analyzed Pay Schedule 2 and 3 projects to determine if a discernable smoothness difference existed when specifying Pay Schedule 2 rather than Pay Schedule 3. The short answer is that there is no discernable difference when Pay Schedules 2 and 3 are selected for similar construction scopes.

Table 14 shows that Pay Schedule 2 projects are on average 0.85 in./mi. smoother than Pay Schedule 3 projects. An IRI difference of 0.85 in./mi. is most likely within the repeatability range for multiple measurements across the same roadway and could within reason be considered the same value. The only noticeable difference between the two pay schedules occurs at the 95th percentile. Pay Schedule 3 projects appear to be rougher at the roughest end of the distribution. This most likely has to do with preexisting conditions rather than construction techniques or quality. Figure 15 shows that the cumulative IRI curves for Pay Schedules 2 and 3 are almost identical, with a slight diversion above 75 percent where Pay Schedule 3 post-construction IRI values are slightly rougher.

Table 14. Pay Schedule 2 versus Pay Schedule 3 Post-construction IRI Values.

	Pay Schedule 2	Pay Schedule 3
No. of Sections	2446	3909
Mean	47.94	48.79
Median	46	45
Maximum	141	213
Minimum	11	7
25th Percentile	39	37
50th Percentile	46	45
75th Percentile	54	56
95th Percentile	73	86

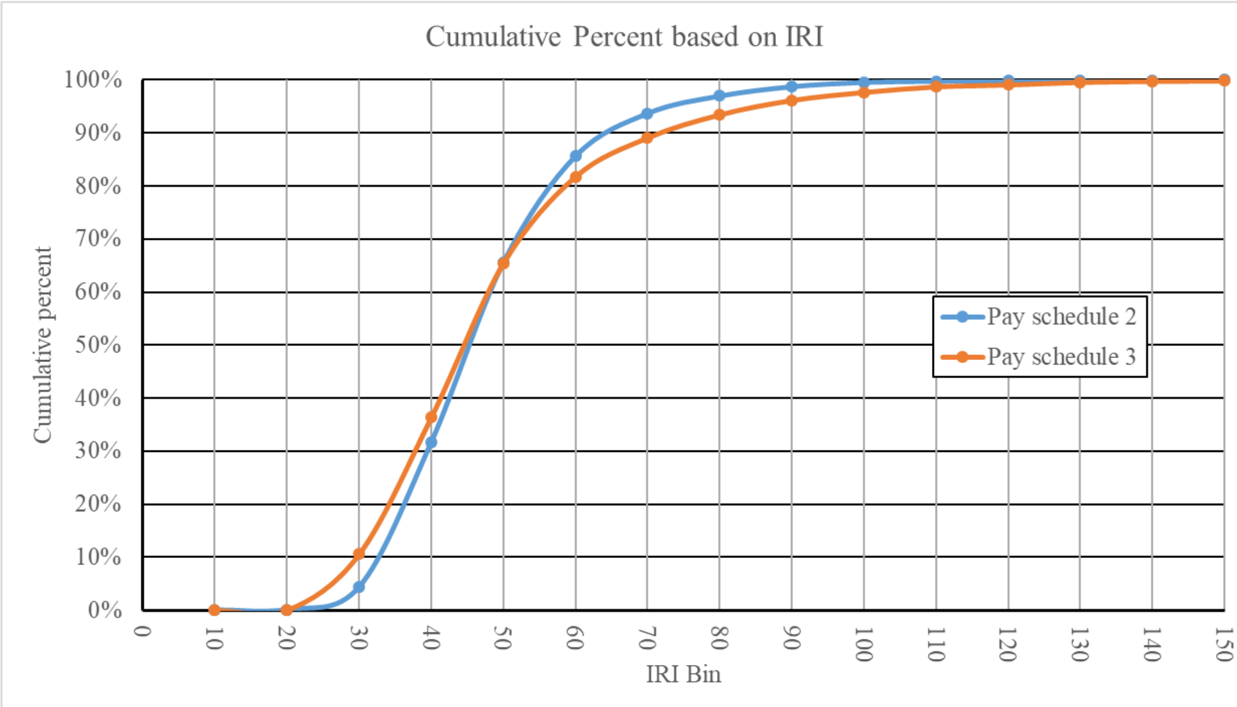

Figure 15. Comparison of Pay Schedule 2 and Pay Schedule 3.

Changing from Pay Schedule 3 to Pay Schedule 2 does not greatly influence the post-construction ride quality; however, as previously discussed, this change would increase the amount of bonus paid to the contractor. This is not surprising because contractors do not use different equipment or techniques on different pay schedule projects. Contractor equipment is typically controlled by production and placement quality control and quality assurance requirements. The requirements do not change regardless of roadway attributes or construction scope.

The expectations established for each construction scope and presented in the guidance tables would help districts currently struggling to have contractors achieve typical smoothness to establish and enforce expectations. This could lead to an improvement in ride quality but quantifying the change across individual districts requires implementing the proposed guidelines and tracking potential changes.

Another opportunity to improve statewide smoothness comes from implementing the bonus/penalty structure proposed in the preceding section. This structure highly incentives contractors to place smoother pavements and becomes more punitive for contractors placing marginal or rough pavements. This type of incentive structure should move poorly performing paving contractors to improve or stop paving altogether. Furthermore, the monetary incentives are enough to ensure good contractors do not become complacent and continue to strive to place pavements with increasing levels of smoothness.

DETERMINE THE APPROPRIATENESS OF A SEPARATE PAY STRUCTURE FOR RIGID VERSUS FLEXIBLE SURFACES

Data used in this study fell into one of eight typical construction scopes. Of those eight scopes, seven were related to HMA surface construction, while the eighth category consisted of data from eight CRCP projects. The CRCP data indicated that concrete pavements are constructed rougher than flexible pavements. This finding was not surprising and has been well known within TxDOT since the 2004 guidance document was drafted. Table 1 is the 2004 guidance document and shows that for CRCP, Pay Schedule 2 was recommended, and for jointed concrete pavements (JCP), Pay Schedule 3 was recommended. These recommendations were made under the assumption that this scope of construction would apply to new construction or major rehabilitation projects, whereas a flexible alternative would have specified Pay Schedule 1. No JCP data were used in this study, nor were any JCP projects present in the FY 2018 letting.

Figure 10 shows that concrete projects have the roughest post-construction ride quality, with over 10 percent of average IRI values higher than 125 in./mi. and almost 35 percent of IRI values considered deficient. Data in Figure 10 consisted of both main lane concrete construction and concrete construction on frontage roads and ramps. Construction of frontage road and ramp lanes often proves difficult from a ride quality perspective because of the number of access points to businesses or side streets. These challenges are akin to the challenges faced during mill and fill construction on C&G facilities.

In order to better understand the smoothness potential on concrete projects, only main lane concrete paving data were sequestered from the full concrete dataset. Data were further collected on a concrete surface before and after the application of NGCS. All three datasets are plotted in Figure 16. The NGCS construction consisted of 318 data collection sections. Figure 16 shows that prior to constructing the NGCS, the location exhibited a similar distribution to new main lane CRCP construction, with a median value between 80 in./mi. and 85 in./mi. and a longer right tail, indicating rougher sections. Applying the NGCS resulted in very smooth pavements with a median value between 30 in./mi. and 35 in./mi., values like those for multiple-lift HMA construction.

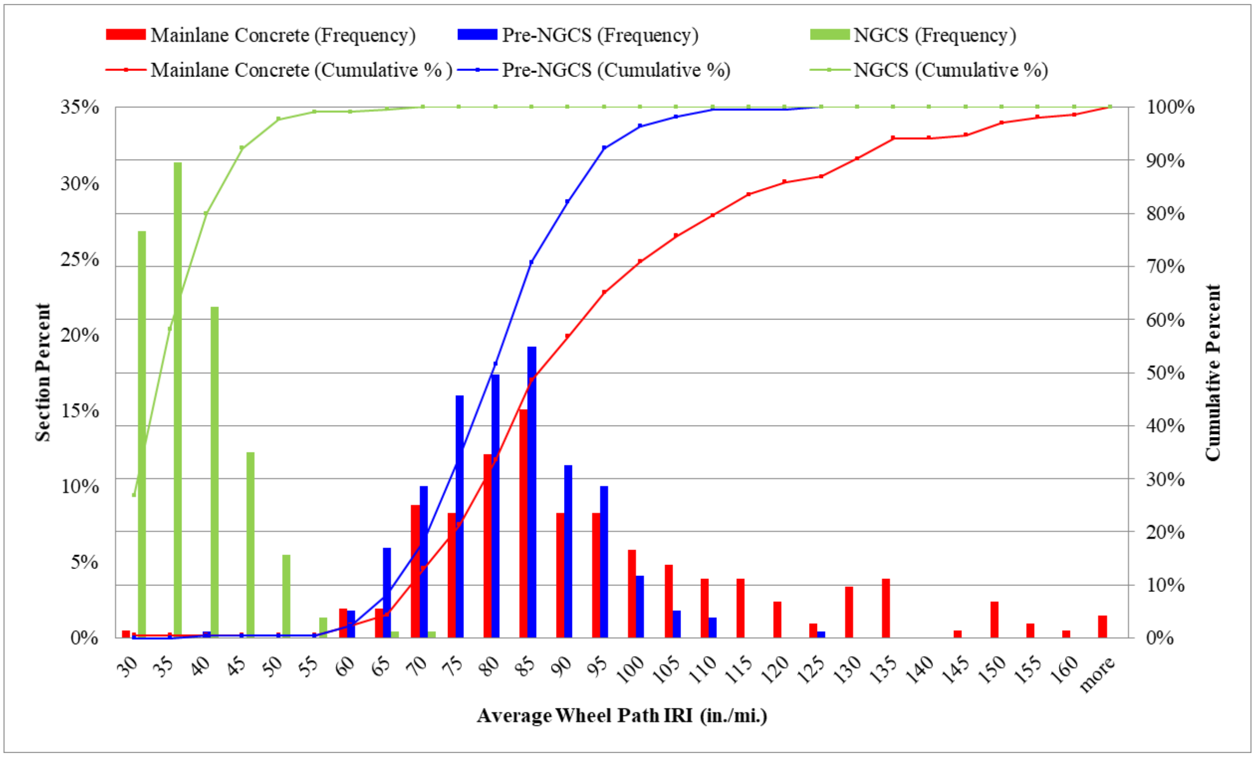

Figure 16. CRCP Main Lane, Pre-NGCS, and NGCS Histograms.

Three of the construction scopes within the eight categories imply new or major rehabilitation construction. These are scarify and reshape with overlay (Group 3), multiple-lift HMA construction (Group 7), and CRCP (Group 8). Plotting these histograms on the same plot creates Figure 17. Without NGCS, CRCP is clearly the roughest of the new construction techniques. Scarify and reshape with an overlay falls between multi-lift HMA and CRCP. The continued roughness of scarify and reshape with overlay is understandable because of the geometrical constraints often encountered in this construction. Scarify and reshape with overlay often occurs on rural sections with limited right of way where lateral support is limited, and residential driveways and intersections impact the final ride quality.

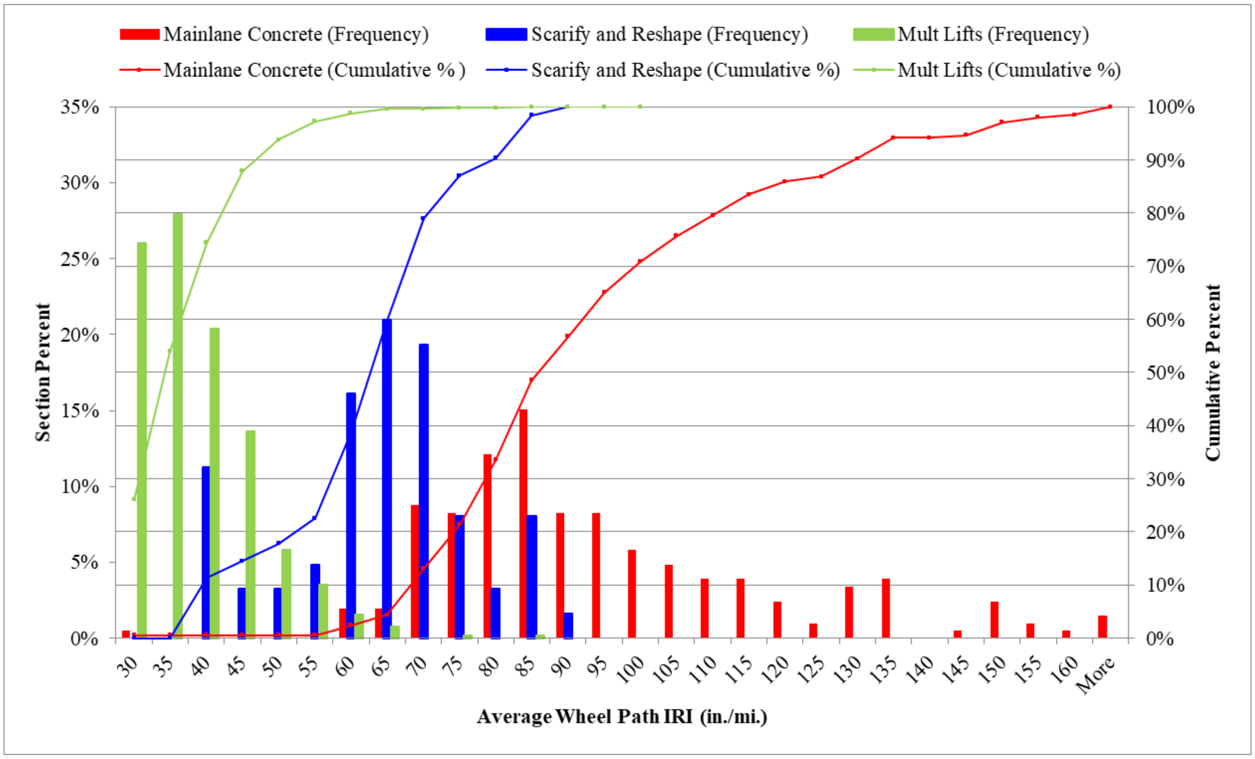

Figure 17. New Construction Scope Comparison.

Applying NGCS to CRCP sections produces a much smoother riding surface. Figure 18 plots the NGCS with multiple-lift HMA projects, and with scarify and reshape with overlay. Figure 18 provides an understanding of what can be achieved on new construction if NGCS is applied to CRCP.

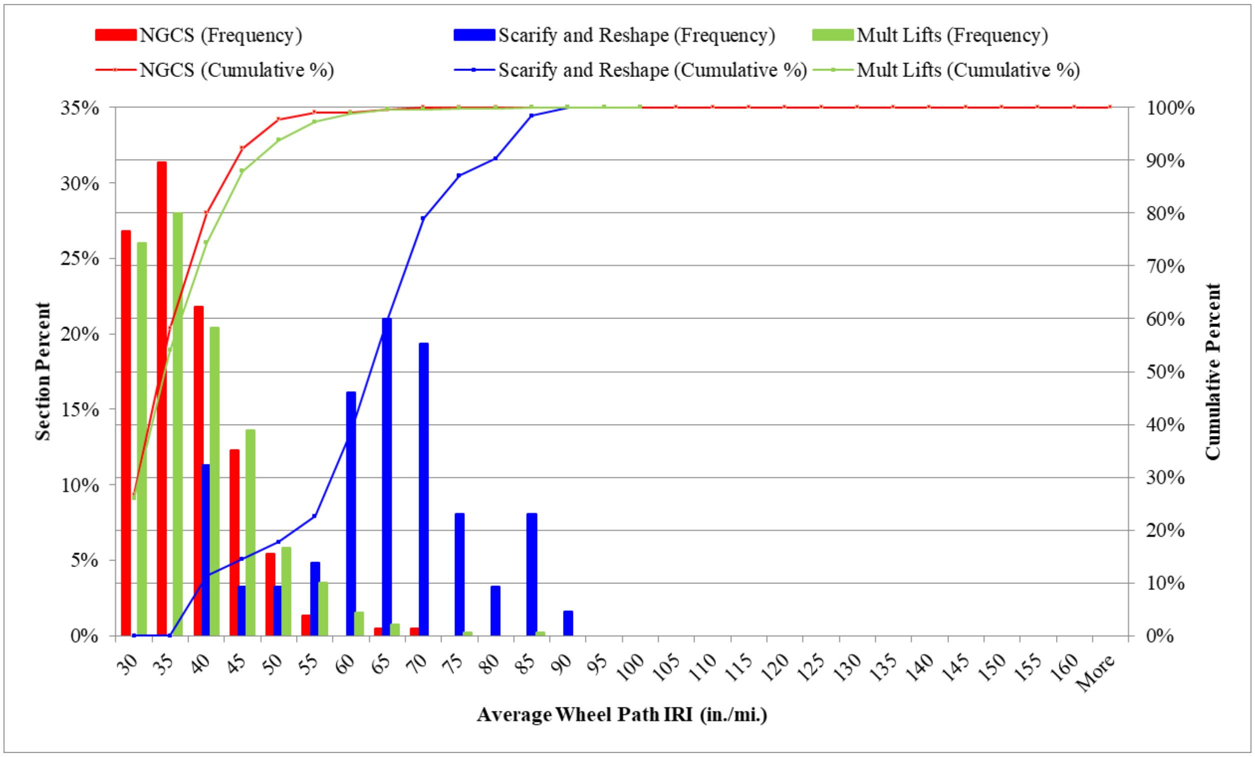

Figure 18. NGCS, Multi-lift HMA, and Scarify and Reshape with Overlay Comparison.

Table 13 recommends a standalone pay schedule for CRCP (Group 8). Table 13 recommends a different pay schedule for each construction group regardless of material type because pay schedules were built from data-driven expectations. However, Table 11 shows that CRCP (Group 8) was the only group without a penalty structure and began paying the contractor bonus at the roughest IRI value of all construction groups. From a policy perspective, this might prove challenging with HMA contractors wondering why their concrete counterparts are not held to the same smoothness standards. While the data suggest that holding them to the same standard is not reasonable, an argument could be made that not having a penalty structure is unfair to HMA alternatives. One might also object to concrete construction receiving a bonus at roughness values higher than any flexible alternative. These arguments are policy arguments and do not reflect the data-driven approach used in this study. Nonetheless, researchers want to point out the inherent issues with Table 11 and Table 13.

The recommended pay schedule for CRCP (Group 8) in Table 11 and Table 13 does not have a penalty structure, in the same way that the existing Pay Schedule 3 does not. While the data indicate this is reasonable, all other construction scopes include a penalty portion, and the existing guidance document recommends Pay Schedule 2 for CRCP, which also includes a penalty portion. Therefore, the research team further evaluated different options for a CRCP (Group 8) pay structure that included a penalty portion. Table 15 shows these results. The original pay structure shown in Table 11 and Table 13 was created using a revenue-neutral approach to have all pay structures have a similar average payout per section. However, unlike asphalt surface projects that currently pay out bonuses on average, CRCP projects do not. Therefore, to create an alternative, the research team built pay structures resulting in the same average penalty per section currently found on CRCP projects. In order to do this, researchers applied a $3,000 penalty to all sections with an IRI larger than 95 in./mi. The average section penalty (or bonus as is the case for the existing Group 8 structure) for each option in Table 15 is as follows:

- Existing Pay Schedule 2 is −$823/section.
- Existing Pay Schedule 3 is −$611/section.
- Option A (Limited Bonus) is −$2,053/section.
- Option B (Limited Bonus and Penalty) is −$655.
- Group 8 (shown in Table 11) is $196/section.
- Group 1 (applied to CRCP) is −$1,236/section.
- Group 3 (applied to CRCP) is −$1,656/section.
- Group 8A is −$939/section.
- Group 8B is −$706/section.

Table 15 has two options where either the bonus or penalty was limited. What is meant by limiting is that in the proposed pay structures in Table 11, the amount of bonus and penalty has been increased to incentivize smooth pavements and disincentivize rougher pavements. Limiting the bonus or penalty helps financially balance the pay structure closer to the existing structure, particularly for Option B, but it does not provide the same incentive or disincentive as for asphalt surfaces. For this reason, Option A and Option B are not recommended. The pay structure for Group 1 (as shown in Table 11) was applied to CRCP projects (Group 8). This was done because Group 1 is the roughest of all asphalt surfaces, representing mill and fill construction constrained by the gutter pan. This pay structure increases the IRI value for a deficient section to 105 in./mi., reducing the number of deficient sections in CRCP construction. However, the penalty structure within Group 1 would increase the amount of penalty paid on CRCP construction by 67 percent per section compared to the existing Pay Schedule 2 and by 100 percent when compared to the existing Pay Schedule 3. This increase in penalty might appear overly punitive to the concrete paving industry. The same is true when applying the pay structure from Group 3. Group 3 represents scarify and reshape with an overlay, which could be considered the roughest new construction or major rehabilitation technique for flexible pavements.

Based on this description, two other options were created that attempted to lower the amount of penalty paid on average while providing incentive and disincentive. The incentive structure for option Group 8A and Group 8B is the same and offers the same opportunities for bonus payment as on a mill and fill constrained by the gutter (Group 1). By doing this, CRCP construction is afforded the same—but not better—chance to receive a bonus as the roughest asphalt surface construction scope. For Group 8A, the $0 pay band is extended to 85 in./mi., rougher than any asphalt surface. Beyond this band is the same linear growth in penalty over a 10 in./mi. span as with all other structures before accelerating to a maximum penalty of $3,000 per section and a deficient threshold at 105 in./mi. Group 8B provides a more lenient penalty structure by extending the $0 pay band to 95 in./mi. (this is similar to existing Pay Schedule 3) before imposing the typical linear penalty structure to the deficient threshold of 105 in./mi. The Group 8B structure creates an average penalty between the current application of Pay Schedules 2 and 3 that is likely the most agreeable to the concrete paving industry. However, this structure fails to disincentivize rough pavements, and therefore, if the goal of new pay structures is to reward highly performing pavements and penalize poorly performing pavements, the structure with Group 8A is recommended.

Table 15. Various Options for a CRCP Pay Structure.

Section IRI (in./mi.)	Existing Pay Schedule 2	Existing Pay Schedule 3	Option A (Limited Bonus)	Option B (Limited Bonus/Penalty)	Group 8 ($/section)	Group 1 ($/section)	Group 3 ($/section)	Group 8A ($/section)	Group 8B ($/section)
20	600	300	1000	500	3000	3000	3000	3000	3000
21	600	300	1000	500	3000	3000	3000	3000	3000
22	600	300	1000	500	3000	3000	3000	3000	3000
23	600	300	1000	500	3000	3000	3000	3000	3000
24	600	300	1000	500	3000	3000	3000	3000	3000
25	600	300	1000	500	3000	3000	3000	3000	3000
26	600	300	1000	500	3000	3000	3000	3000	3000
27	600	300	1000	500	3000	3000	3000	3000	3000
28	600	300	1000	500	3000	3000	3000	3000	3000
29	600	300	1000	500	3000	3000	3000	3000	3000
30	600	300	900	500	3000	3000	3000	3000	3000
31	580	290	850	500	3000	3000	2875	3000	3000
32	560	280	800	500	3000	3000	2750	3000	3000
33	540	270	750	500	3000	3000	2625	3000	3000
34	520	260	700	500	3000	3000	2500	3000	3000
35	500	250	650	500	3000	3000	2375	3000	3000
36	480	240	600	500	3000	2875	2250	2875	2875
37	460	230	550	500	3000	2750	2125	2750	2750
38	440	220	500	500	3000	2625	2000	2625	2625
39	420	210	450	500	3000	2500	1875	2500	2500
40	400	200	400	500	3000	2375	1750	2375	2375
41	380	190	350	500	3000	2250	1625	2250	2250
42	360	180	325	500	3000	2125	1500	2125	2125
43	340	170	300	500	3000	2000	1375	2000	2000
44	320	160	275	500	3000	1875	1250	1875	1875
45	300	150	250	500	3000	1750	1125	1750	1750
46	280	140	225	500	3000	1625	1000	1625	1625
47	260	130	200	500	3000	1500	875	1500	1500
48	240	120	175	500	3000	1375	750	1375	1375
49	220	110	150	500	3000	1250	625	1250	1250
50	200	100	125	500	3000	1125	500	1125	1125
51	180	90	100	500	3000	1000	450	1000	1000
52	160	80	75	500	3000	875	400	875	875
53	140	70	50	500	3000	750	350	750	750
54	120	60	25	500	3000	625	300	625	625
55	100	50	0	500	3000	500	250	500	500
56	80	40	0	480	2810	450	200	450	450
57	60	30	0	460	2645	400	150	400	400
58	40	20	0	440	2480	350	100	350	350
59	20	10	0	420	2315	300	50	300	300
60	0	0	0	400	2150	250	0	250	250

Table 15. Various Options for a CRCP Pay Structure (Continued).

Section IRI (in./mi.)	Existing Pay Schedule 2	Existing Pay Schedule 3	Option A (Limited Bonus)	Option B (Limited Bonus/Penalty)	Group 8 ($/section)	Group 1 ($/section)	Group 3 ($/section)	Group 8A ($/section)	Group 8B ($/section)
60	0	0	0	400	2150	250	0	250	250
61	0	0	0	380	1985	200	0	200	200
62	0	0	0	360	1820	150	0	150	150
63	0	0	0	340	1655	100	0	100	100
64	0	0	0	320	1490	50	0	50	50
65	0	0	-100	300	1325	0	0	0	0
66	0	0	-200	280	1160	0	0	0	0
67	0	0	-300	260	995	0	0	0	0
68	0	0	-400	240	830	0	0	0	0
69	0	0	-500	220	665	0	0	0	0
70	0	0	-600	200	500	0	-50	0	0
71	0	0	-700	180	450	0	-100	0	0
72	0	0	-800	160	400	0	-150	0	0
73	0	0	-900	140	350	0	-200	0	0
74	0	0	-1000	120	300	0	-250	0	0
75	0	0	-1100	100	250	0	-300	0	0
76	-20	0	-1200	80	200	-50	-350	0	0
77	-40	0	-1300	60	150	-100	-400	0	0
78	-60	0	-1400	40	100	-150	-450	0	0
79	-80	0	-1500	20	50	-200	-500	0	0
80	-100	0	-1600	0	0	-250	-655	0	0
81	-120	0	-1700	0	0	-300	-810	0	0
82	-140	0	-1800	0	0	-350	-965	0	0
83	-160	0	-1900	0	0	-400	-1120	0	0
84	-180	0	-2000	0	0	-450	-1275	0	0
85	-200	0	-2100	0	0	-500	-1430	0	0
86	-220	0	-2200	0	0	-625	-1585	-50	0
87	-240	0	-2300	0	0	-750	-1740	-100	0
88	-260	0	-2400	0	0	-875	-1895	-150	0
89	-280	0	-2500	0	0	-1000	-2050	-200	0
90	-300	0	-2600	0	0	-1125	-2205	-250	0
91	-320	0	-2700	0	0	-1250	-2360	-300	0
92	-340	0	-2800	0	0	-1375	-2515	-350	0
93	-360	0	-2900	0	0	-1500	-2670	-400	0
94	-380	0	-3000	0	0	-1625	-2825	-450	0
95	-400	0	-3000	-25	0	-1750	-3000	-500	0
96	Deficient	Deficient	Deficient	-50	0	-1875	Deficient	-750	-50
97				-75	0	-2000		-1000	-100
98				-100	0	-2125		-1250	-150
99				-125	0	-2250		-1500	-200
100				-150	0	-2375		-1750	-250
101				-175	0	-2500		-2000	-300
102				-200	0	-2625		-2250	-350
103				-225	0	-2750		-2500	-400
104				-250	0	-2875		-2750	-450
105				-275	0	-3000		-3000	-500
>105				Deficient	Deficient	Deficient		Deficient	Deficient

CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION

CONCLUSIONS

The existing guidance document TxDOT uses to select a pay schedule on a paving project is over 15 years old. The use of the guidance document varies across TxDOT, and the selection of a pay schedule does not always agree with the guidance provided. Additionally, the existing guidance document was built without extensive data analysis—data that are now readily available. This project found that while each highway project is unique, the paving aspect of each project could be classified into one of eight typical construction scopes:

1. Group 1: mill and fill in the outside lane of a C&G section.
2. Group 2: mill and fill when the mat is not constrained to a gutter pan.
3. Group 3: scarify and reshape the existing base with an overlay greater than or equal to 1.5 in.
4. Group 4: HMA overlay with a depth greater than or equal to 1.5 in.
5. Group 5: mill and overlay with a mat thickness deeper than 1.5 in.
6. Group 6: HMA overlay with a depth less than 1.5 in.
7. Group 7: multiple HMA lifts with a depth greater than or equal to 1.5 in.
8. Group 8: CRCP.

Additionally, construction of NGCS could create another group. However, NGCS currently uses its own special specification (i.e., SS 3012) with its own pay structure.

Post-construction ride quality data on 70 paving projects consisting of 8,448 sections and over 825 lane miles of paving were analyzed to determine achievable post-construction smoothness. This data-driven approach resulted in an understanding of the distribution of post-construction ride quality in each of the eight construction groups. This understanding helped develop a simplified guidance table to replace the existing guidance document. The new guidance table selects an existing pay schedule based on the statistical distribution of post-construction ride quality for a work type and was shown in Table 9.

Because contractors currently achieve bonus on 80 percent of asphalt surface sections, using the proposed guidance table would result in TxDOT paying more bonuses without necessarily improving statewide ride quality. The data-driven approach used in this study indicated that TxDOT should specify Pay Schedule 1 or 2 more often because the industry can achieve that level of smoothness on most construction groups. However, the research also indicated that prescribing Pay Schedule 1 or 2 would not necessarily improve statewide smoothness under the existing pay structure. Therefore, the guidance table (i.e., Table 9) should be used for informational purposes to understand post-construction expectations but should not necessarily be used to select a pay schedule unless pay structures are also changed. Currently, TxDOT pays approximately $8 million per year in ride bonus. Selecting Pay Schedules 1 and 2 using the proposed guidance table would result in TxDOT paying approximately $9.1 million annually (i.e., a 13 percent increase) without the contractor making any adjustments to improve smoothness.

Because it appears unlikely that simply selecting a new pay schedule will lead to improved statewide smoothness, the project developed new pay structures. These new pay structures incentivize constructing smoother pavements by increasing the bonus available. Furthermore, construction of average pavements within a work group no longer receives a bonus payment. Finally, the penalty structure disincentivizes the construction of rough pavements to a level where contractors should conscientiously consider pavement smoothness during construction.

Table 13 shows the final pay structure recommended. The Group 8 (CRCP) structure has been modified to include a bonus and penalty structure similar to that for asphalt surface alternatives, while acknowledging that data indicate that smoothness in Group 8 cannot achieve the same levels as asphalt alternatives. Furthermore, because the NGCS data lead to smoothness near that attained through multi-lift HMA construction, researchers recommend eliminating the pay structure in SS 3012 and using Group 1 for NGCS construction. Eliminating the pay structure in SS 3012 would unite all pay requirements under Item 585 while establishing pay structures for different work groups.

Table 13 represents a substantial departure from the existing pay structure in Item 585. However, the precedent of using an individual pay structure for a specific work type was established with SS 3012 for NGCS. Table 13 continues this methodology but builds it out for the eight typical construction paving types used in Texas. Each highway project is unique and has its own characteristics, but the typical section of a project usually includes a predominant paving type. For this reason, the new guidance document and modified pay structures should be implemented simultaneously. Furthermore, the groups were established in such a way that TxDOT can select multiple groups on a single project. For example, on a multi-lane urban project with C&G, Group 1 should be used in the outside lane and Group 2 in all other lanes. For a widening project, such as a Super 2, where the new outside lane has multiple lifts of HMA, Group 7 is appropriate. If the existing roadbed is milled and overlaid to match the widening, the existing lanes should use Group 5. By selecting pay schedules and structures in this way, TxDOT makes its decision based on what is expected from the contractor. The structure of each proposed pay schedule provides the contractor a larger financial incentive to provide a superior product. Similarly, the disincentive is also much greater. Researchers believe that implementing this type of structure has the potential to improve overall statewide smoothness, whereas the current structure, even using the proposed guidance table, does not.

Finally, it is always prudent to use preconstruction data to assist in the decision-making process. Table 13 provides the regression equations developed in this project to assist with post-construction prediction. These equations apply to both network-level and project-level data. The pay schedule can still be selected using the predominant construction group; however, users can also plot the predicted post-construction values on the bonus/penalty curve graphs to see which graph fits best. The bonus/penalty curve that fits the predictions the best should be used to select the pay structure or at least verify that the pay structure selected based on work group is reasonable.

RECOMMENDATIONS AND IMPLEMENTATION

Implementation of Guidance Document for Information Purposes

Without simultaneously changing the pay structure, the research team recommends implementing the guidance table for informational purposes only. This implementation project would work with districts to educate district personnel on the post-construction expectations for different construction types. In addition to this, the project should review available post-construction ride quality data within the district to ensure it follows the statewide trends used to develop the guidance document. If there are major differences, the guidance table could be used to select a pay schedule to improve ride quality. The recommended platform for this implementation is a district visit to discuss ride quality with the director of construction, area engineers, and assistant area engineers. The delivery could occur in a virtual environment, but researchers recommend having meetings individually with districts to discuss district-specific issues with ride quality.

Implementation of the Guidance Document and New Pay Structures in Pilot Districts

To begin moving to a specification change with new pay structures, researchers recommend selecting up to four pilot districts to implement the guidance document and new pay structures. The use of the new pay structures would require a special specification unless it was approved to make the changes through a general note. The research team would work with districts during the design of paving projects to collect preconstruction project-level data and predict the post-construction quality. Using this information, the guidance table, and the scope of work, a pay structure would be selected. Researchers would track the project through construction and attend the pre-paving meeting to ensure all parties understand the modified requirements. If required, researchers can present the modifications to the local Association of General Contractors to assuage concerns.

Following construction, post-construction data would be collected and analyzed. Ideally, this project would use districts where the new guidance and pay structure could be used, but similar projects would use the existing structure. This would allow for a side-by-side comparison of projects to determine if the new structure was resulting in smoother pavements. Additionally, the financial impacts to the contractor and TxDOT could be measured. Performing this project would substantially strengthen efforts to completely rewrite the pay structure in Item 585 before the next specification rewrite. Additionally, it would help prepare the contracting community for the change and help identify any additional needs before rewriting the specification for statewide deployment. This would be an intense implementation project requiring coordination with multiple districts and contractors. Ideally, the dataset would be large, consisting of 20 or more paving projects.

Specification Rewrite

A rewrite of the pay structure in the existing Item 585 specification can occur in a standalone fashion based on the results of this research project. At a minimum, the research team recommends performing a specification rewrite with the implementation of deploying the new guidance document as described previously. Additionally, a task should be included in the specification rewrite to meet with districts after the rewrite to describe changes and how the new guidance table applies. The team could begin to draft a new specification immediately that can be implemented as a special specification prior to the compilation of the new specification book.

ADDITIONAL RESEARCH

Localized Roughness Research

While this project created a data-driven approach to understand post-construction ride quality expectations for typical paving types, enough data were not available to draw conclusions about the impact to localized roughness. Researchers recommend developing a research project to select up to four districts to participate. In this project, preconstruction ride quality data should be collected within three months of beginning paving. The ride quality data should be used to identify localized roughness locations and then visually verify them. The locations should be georeferenced and marked prior to paving. Researchers will observe paving operations to identify how paving was conducted over the localized roughness and note any other construction techniques that might have improved or impaired smoothness. Following construction, post-construction ride data would be collected and analyzed to draw conclusions for localized roughness. This type of project needs a robust dataset and requires significant field work during paving operations. This project would be difficult to complete in less than two years.

Study of Scarify and Reshape without an Overlay Ride Quality

The scarify and reshape with overlay data provided insight into the challenges associated with rehabilitating the rural Farm-to-Market network. The age of this network continues to require rehabilitation projects across the state. Many of these projects do not include an overlay; rather, they use multi-course surface treatments as the final riding surface. TxDOT has performed research in the past on the smoothness attainable through this type of construction, and the smoothness requirements applied to Item 247 in some projects was the result. However, it might be time to revisit the attainable smoothness considering the results of this project and evaluate the use of a bonus/penalty pay structure on these types of projects. If this research project were undertaken and a bonus/penalty structure was developed, researchers would likely recommend creating an additional work group to include in Item 585 so that all ride requirements can reside in a single specification item.

APPENDIX A: GUIDANCE DOCUMENT DISCREPANCIES

This appendix includes examples from plan sets where the general note(s) contradicted or nullified the existing guidance document or the Item 585 specification as a whole. The list below includes 11 projects where these types of notes existed.

- CSJ: 0413-03-044 on US 87 in Wilson County of the San Antonio District:
    - 103 bid days let in February 2018.
    - Scope: Complete reconstruction with thick HMA and a Superpave D surface.
    - Recommended pay schedule of 1, but the general note waived the requirement, as shown in Figure 19.

--Item 585--
Ride quality requirements are waived.

Figure 19. General Note Waiving the Ride Requirement.

- CSJ: 0521-05-145 on IH 410 in Bexar County of the San Antonio District:
    - 41 bid days let in February 2018.
    - Scope: 2-in. unconfined milling with a 2-in. overlay of Superpave D on the frontage road.
    - Recommended pay schedule of 3, but the same general note as shown in Figure 19 was present.
- CSJ: 0850-04-027 on FM 775 in Wilson County of the San Antonio District:
    - 85 bid days let in February 2018.
    - Scope: Milling with a 2-in. dense-graded HMA lift.
    - Recommended pay schedule of 3, but the same general note as shown in Figure 19 was present.
- CSJ: 0073-05-070 on IH 37 in Atascosa County of the San Antonio District:
    - 143 bid days let in April 2018.
    - Scope: Either HIR or 2-in. unconfined mill with 2-in. overlay and a 1-in. thin-bonded permeable friction course as the surface.
    - Recommended pay schedule of 2, but the same general note as shown in Figure 19 was present.
- CSJ: 0253-03-072 on US 281 in Comal County of the San Antonio District:
    - 57 bid days let in April 2018.
    - Scope: 1.5-in. PFC overlay.
    - Recommended pay schedule of 2, but no item was activated in the estimate, and the confusing general note shown in Figure 20 was present.

--Item 585--
Use Surface Test Type B, pay adjustment schedule 1 (one) to evaluate ride quality of travel lanes.

Ride quality requirements are waived.

Figure 20. Conflicting General Note.

- CSJ: 3508-01-028 on SH 151 in Bexar County of the San Antonio District:
  - 202 bid days let in May 2018.
  - Scope: 2-in. Superpave D overlay.
  - Recommended pay schedule of 2, but no item was activated, and the confusing general note in Figure 21 existed in the plans.

--Item 585--
Use Surface Test Type B, pay adjustment schedule A to evaluate ride quality of travel lanes.

Figure 21. General Note Confusing Test Type and Pay Schedule.

Details associated with the five projects that did not enforce Item 585 are as follows:

- CSJ: 6307-43-001 on US 79 in Milam County of the Bryan District:
  - 38 bid days let in January 2017.
  - Scope: Pure 2-in. mill and fill with Superpave C on a two-lane undivided highway.
  - Recommended pay schedule is 3.
- CSJ: 0185-04-045 on US 190 in Milam County of the Bryan District:
  - 82 bid days let in December 2015.
  - Scope: 2.5-in. mill and inlay with a 2-in. overlay of Superpave D on a two-lane undivided highway.
  - Recommended pay schedule is 3.
- CSJ: 3595-01-017 on SH 275 in Galveston County of the Houston District:
  - 75 bid days let in April 2017.
  - Scope: ¾-in. TOM F overlay followed by a 1-in. TOM C overlay on a multi-lane facility.
  - Recommended pay schedule is 2.
- CSJ: 0219-02-013 on FM 1016 in Hidalgo County of the Pharr District:
  - 402 bid days let in November 2016.
  - Scope: New CRCP construction.
  - Recommended pay schedule is 2.
- CSJ: 0043-05-104 on US 70 in Wilbarger County of the Wichita Falls District:
  - 55 bid days let in December 2015.

- Scope: 1.25-in. PFC overlay on a divided highway.
- Recommended pay schedule is 3.

Analyzing the randomly selected projects for agreement with the guidance document resulted in similar results to the FY 2018 project analysis. Figure 22 shows the results; most projects follow the guidance document, but when the project does not, less stringent pay schedules are prescribed more often than more stringent ones.

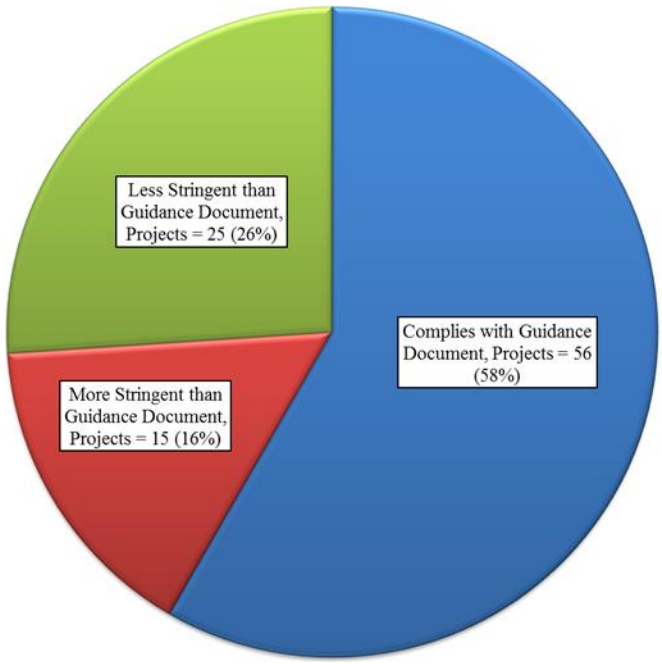

Figure 22. FY 2016 and FY 2017 Pay Schedule Selection and Guidance Document Agreement.

APPENDIX B: POST-CONSTRUCTION LEFT AND RIGHT WHEEL PATH IRI VALUES

The main body of this report includes the average post-construction IRI values for each work group. This appendix includes individual plots for each wheel path for each construction group.

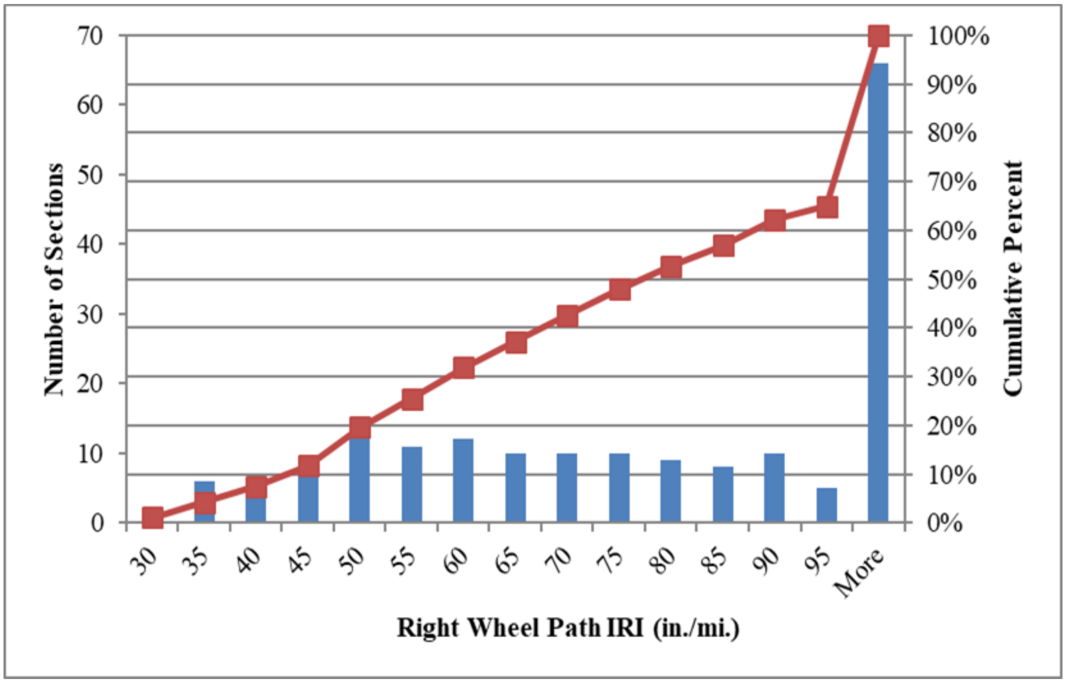

Figure 23. Right Wheel Path IRI for Mill and Fill in Outside Lane of C&G (Group 1).

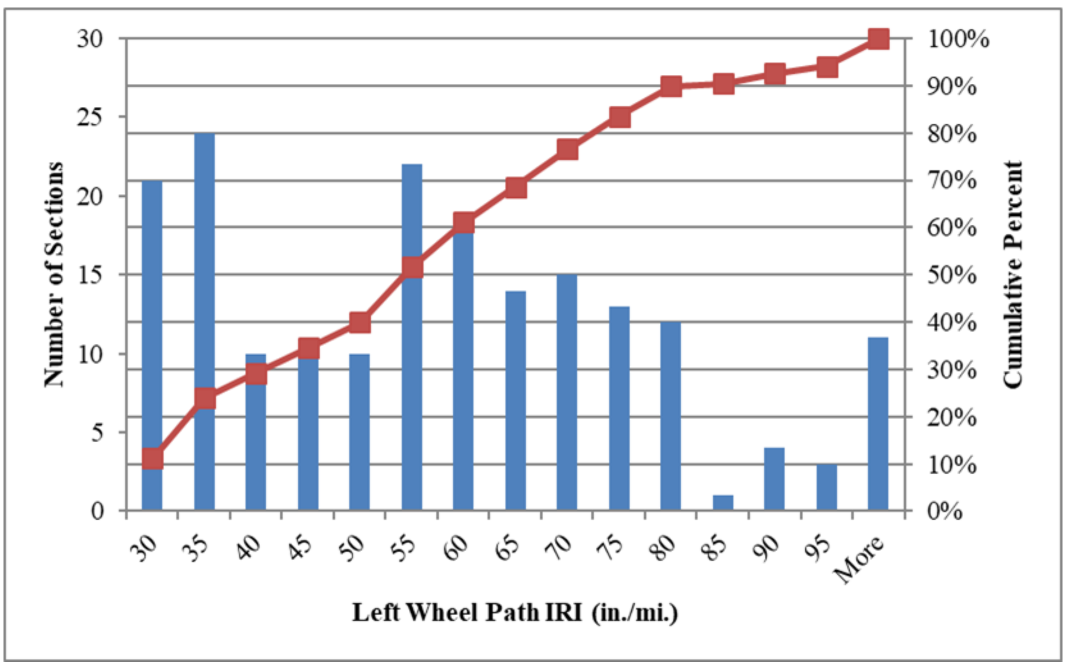

Figure 24. Left Wheel Path IRI for Mill and Fill in Outside Lane of C&G (Group 1).

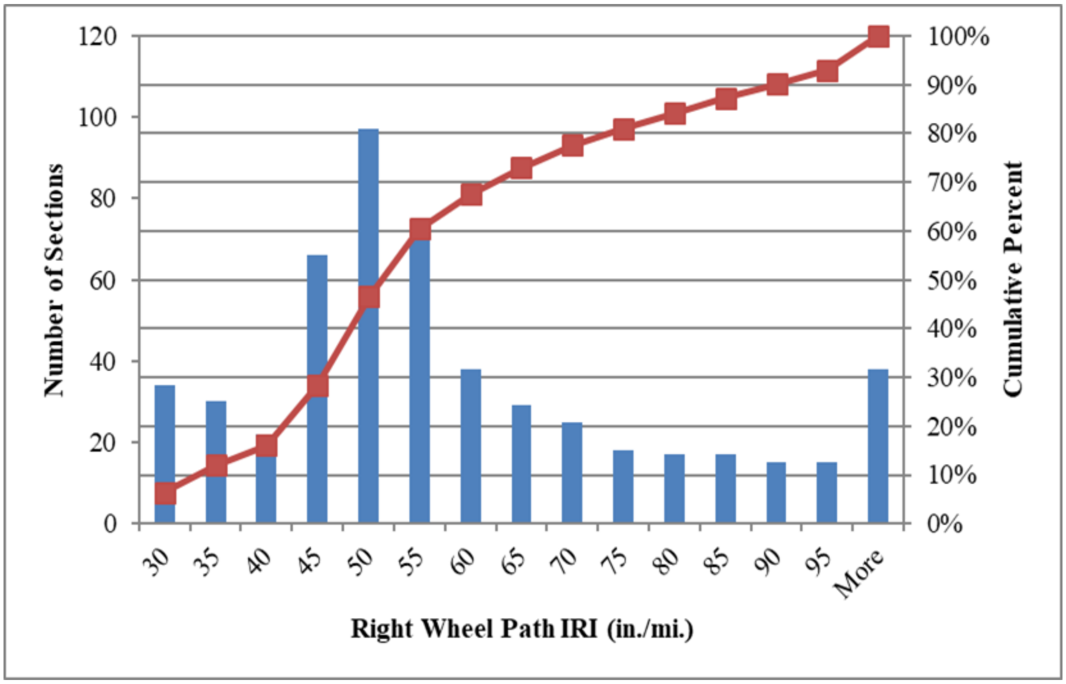

Figure 25. Right Wheel Path IRI for Mill and Fill Not Constrained by Gutter (Group 2).

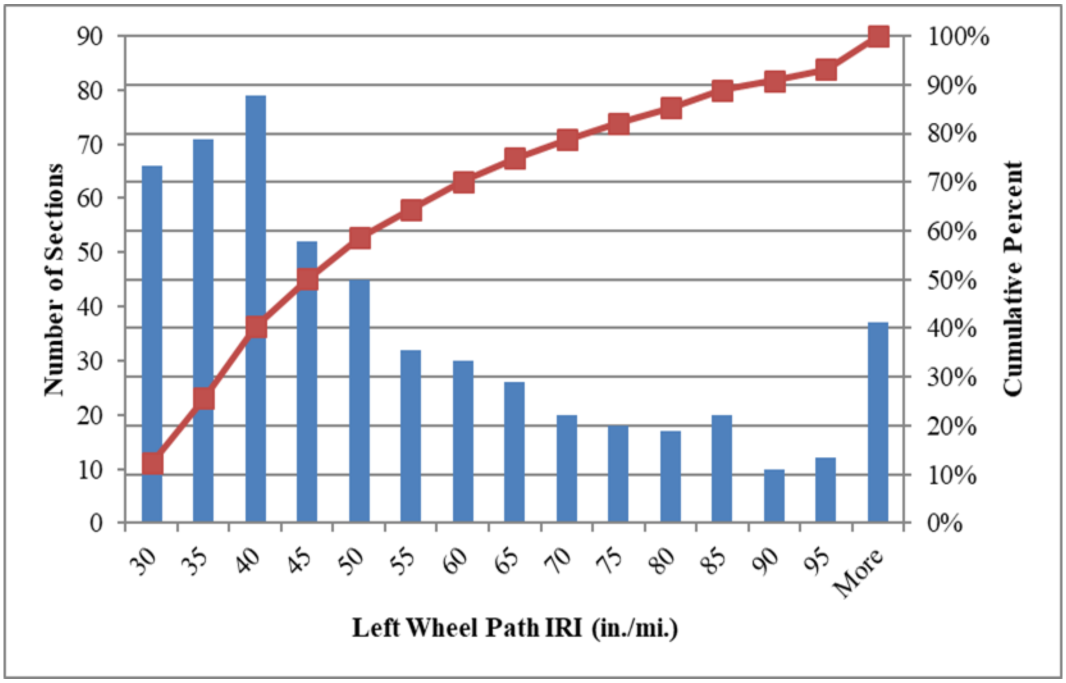

Figure 26. Left Wheel Path IRI for Mill and Fill Not Constrained by Gutter (Group 2).

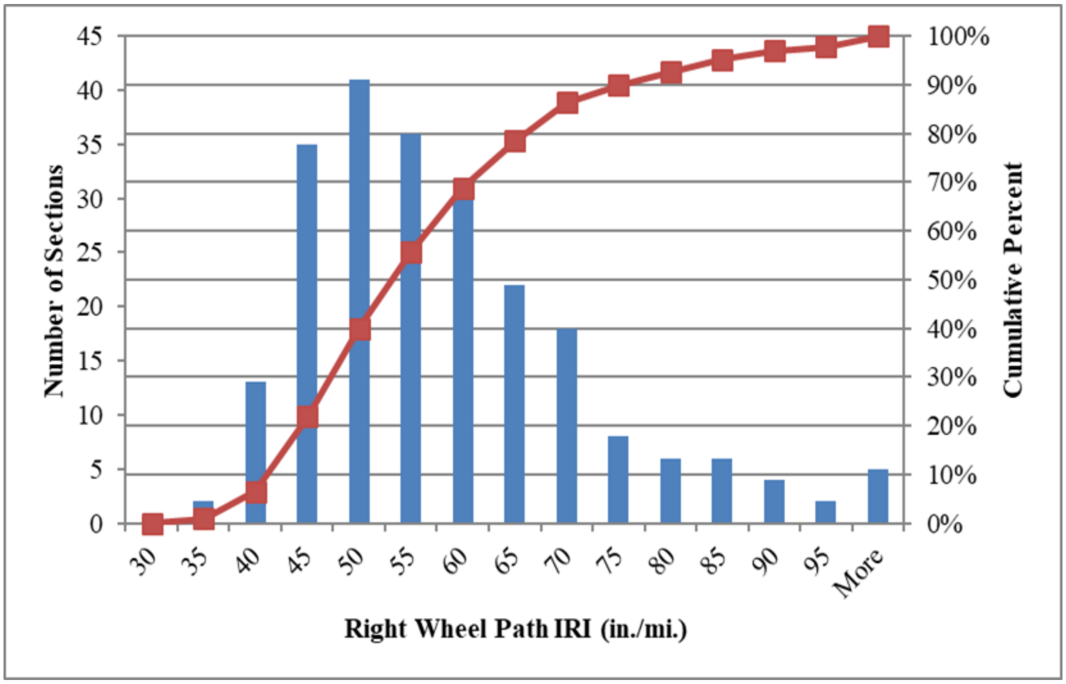

Figure 27. Right Wheel Path IRI for Scarify with Overlay Projects Greater than or Equal to 1.5 in. (Group 3).

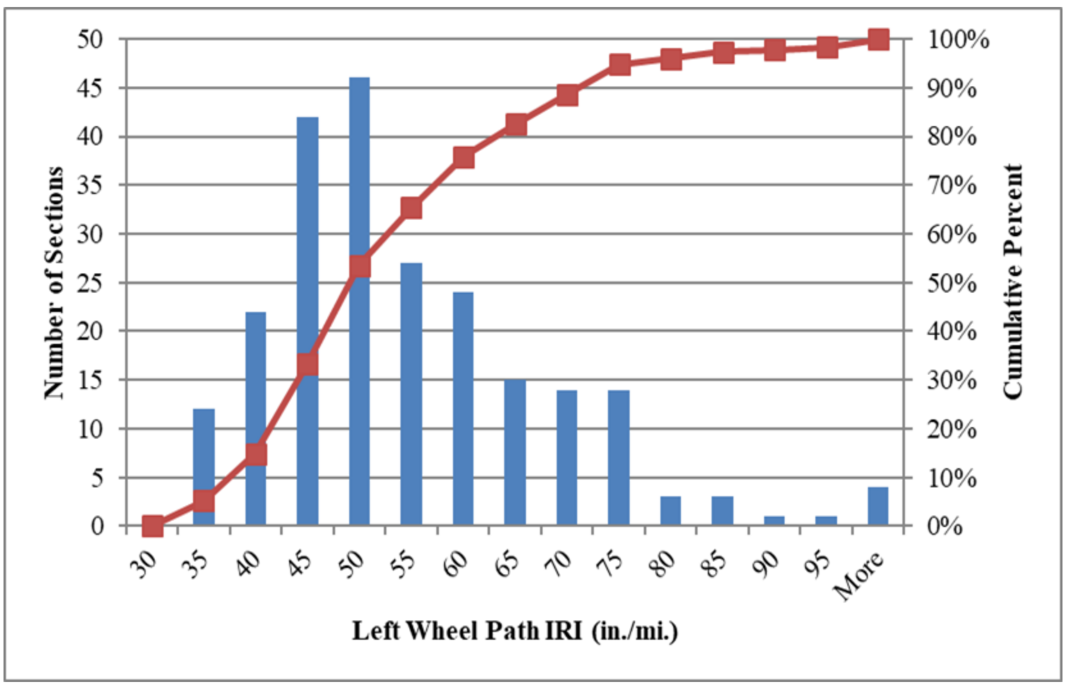

Figure 28. Left Wheel Path IRI for Scarify with Overlay Projects Greater than or Equal to 1.5 in. (Group 3).

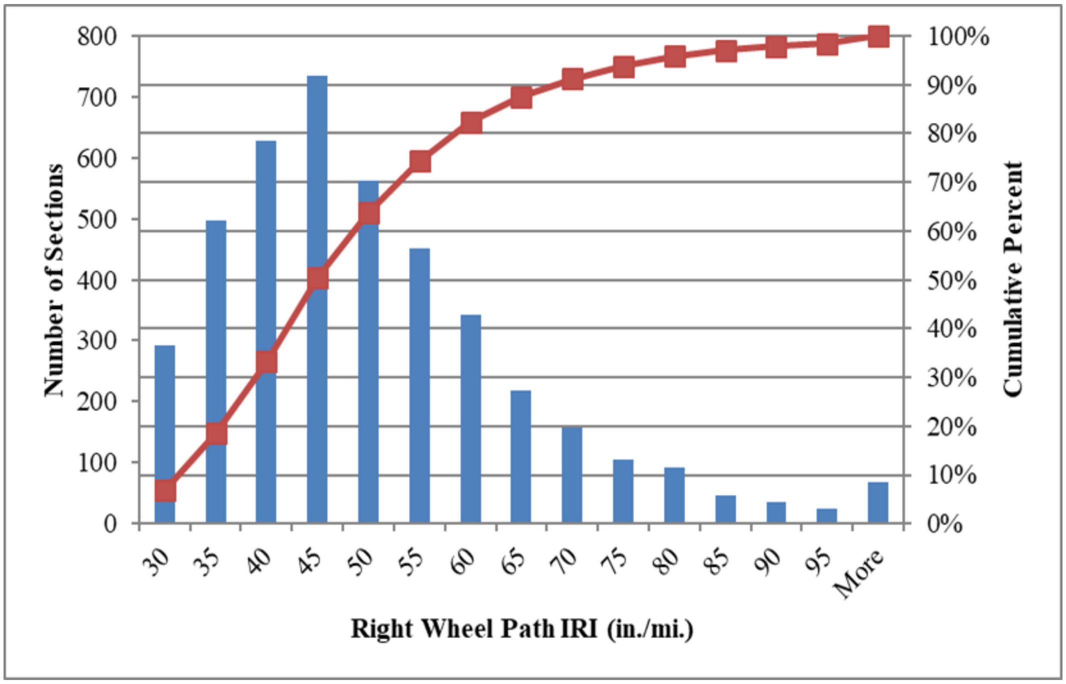

Figure 29. Right Wheel Path IRI for Overlay Greater than or Equal to 1.5 in. (Group 4).

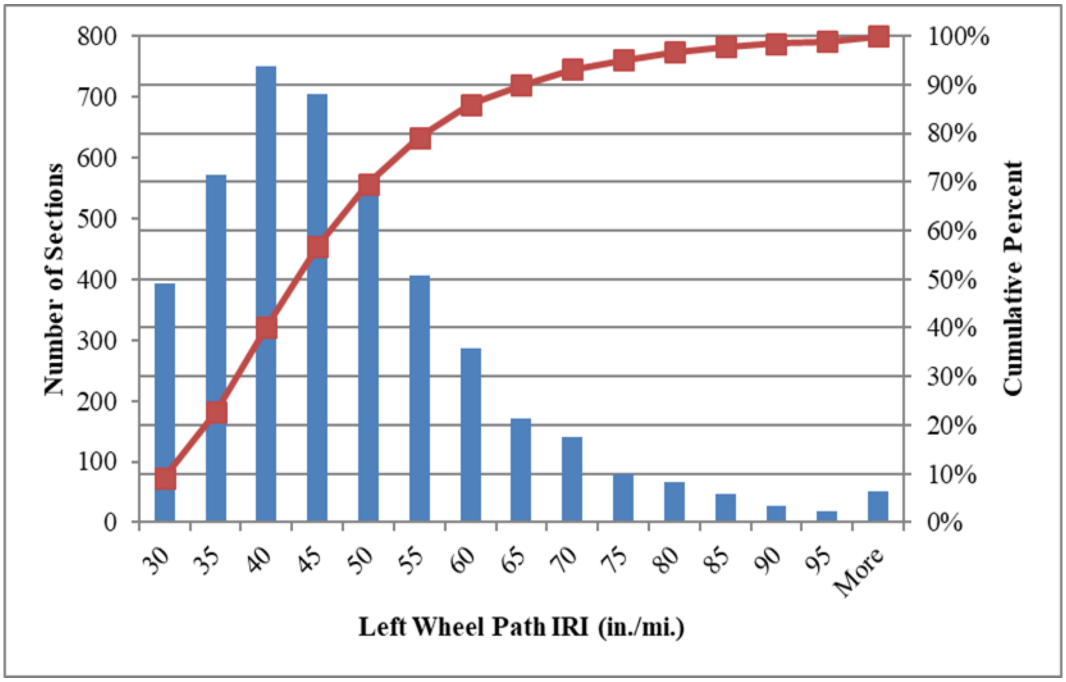

Figure 30. Left Wheel Path IRI for Overlay Greater than or Equal to 1.5 in. (Group 4).

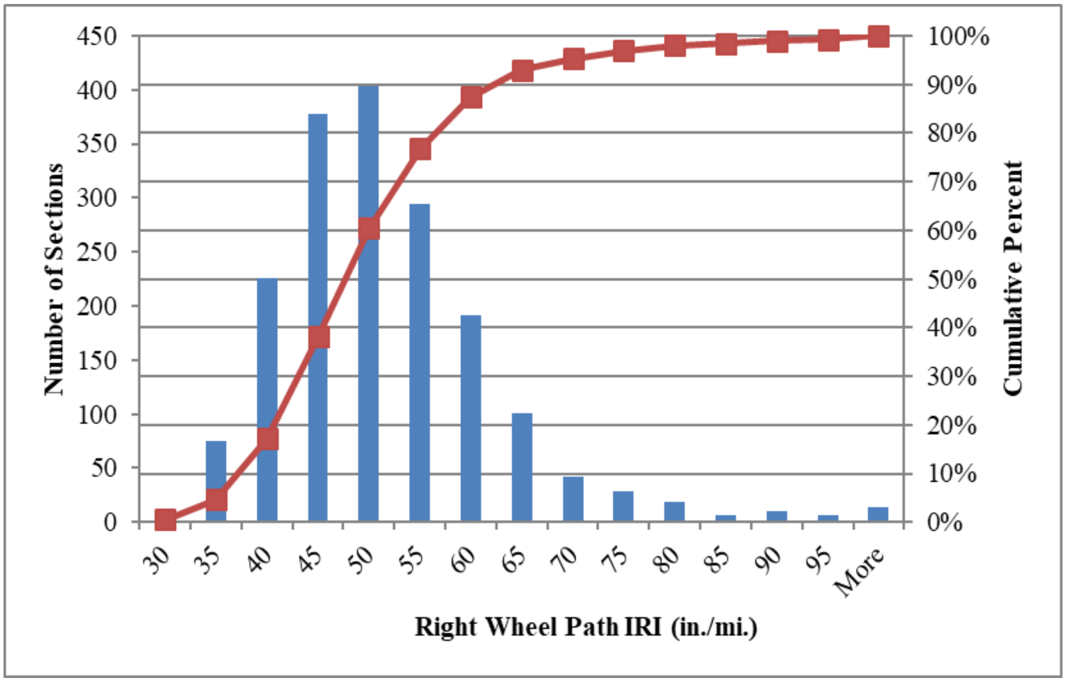

Figure 31. Right Wheel Path IRI Mill and Overlay Greater than or Equal to 1.5 in. (Group 5).

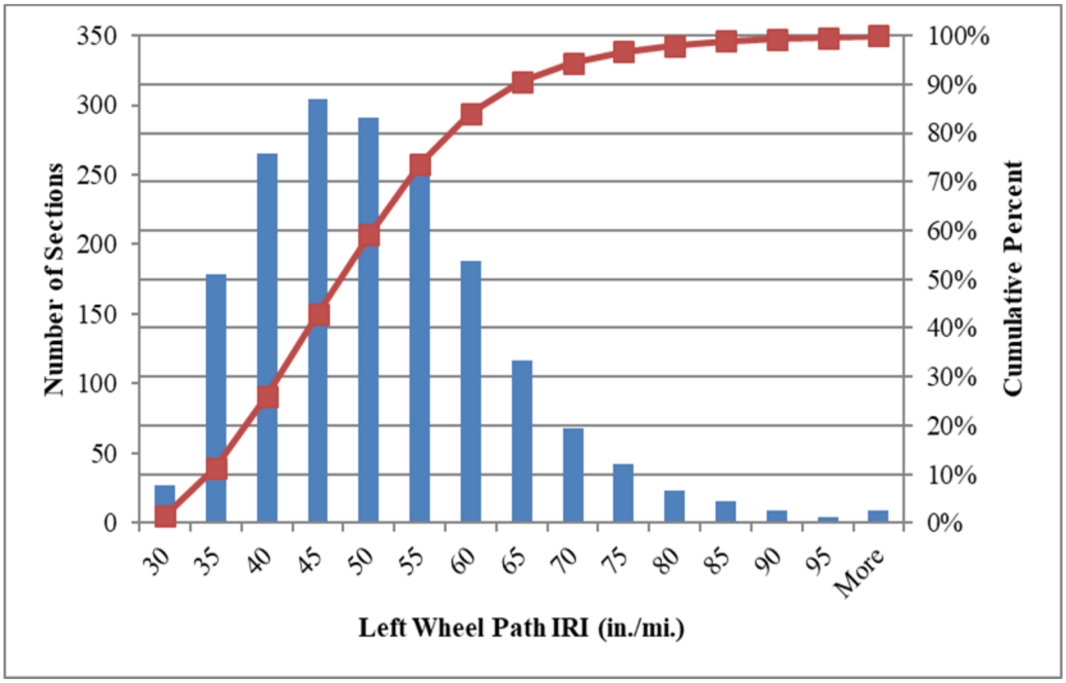

Figure 32. Left Wheel Path IRI Mill and Overlay Greater than or Equal to 1.5 in. (Group 5).

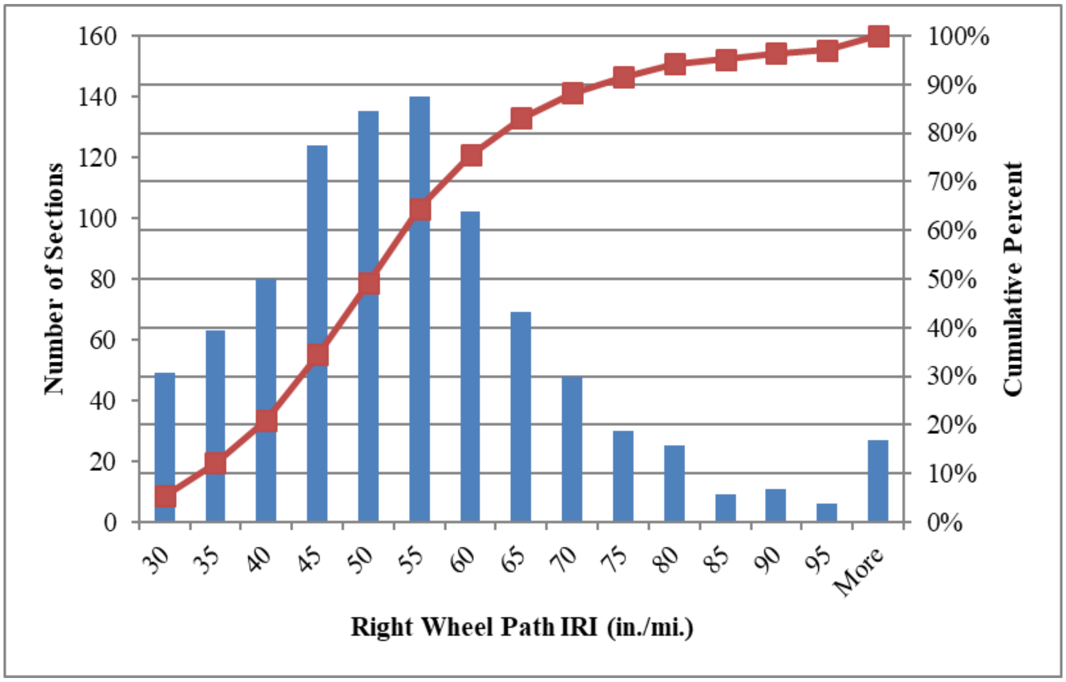

Figure 33. Right Wheel Path IRI for Overlay Less than 1.5 in. (Group 6).

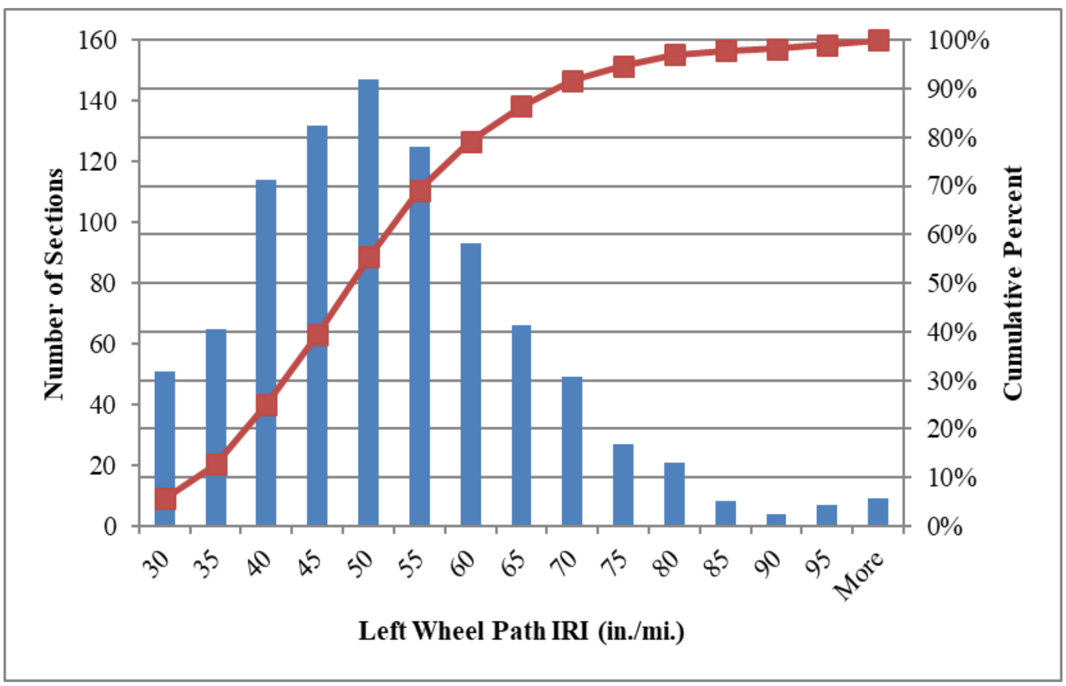

Figure 34. Left Wheel Path IRI for Overlay Less than 1.5 in. (Group 6).

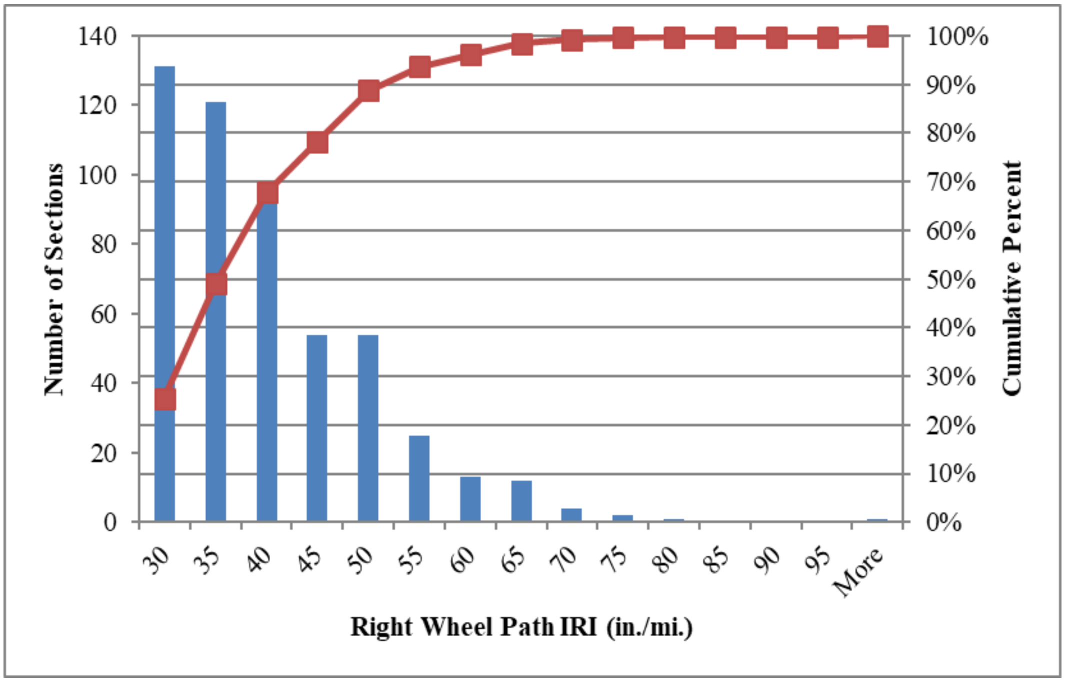

Figure 35. Right Wheel Path IRI for Multi-lift HMA (Group 7).

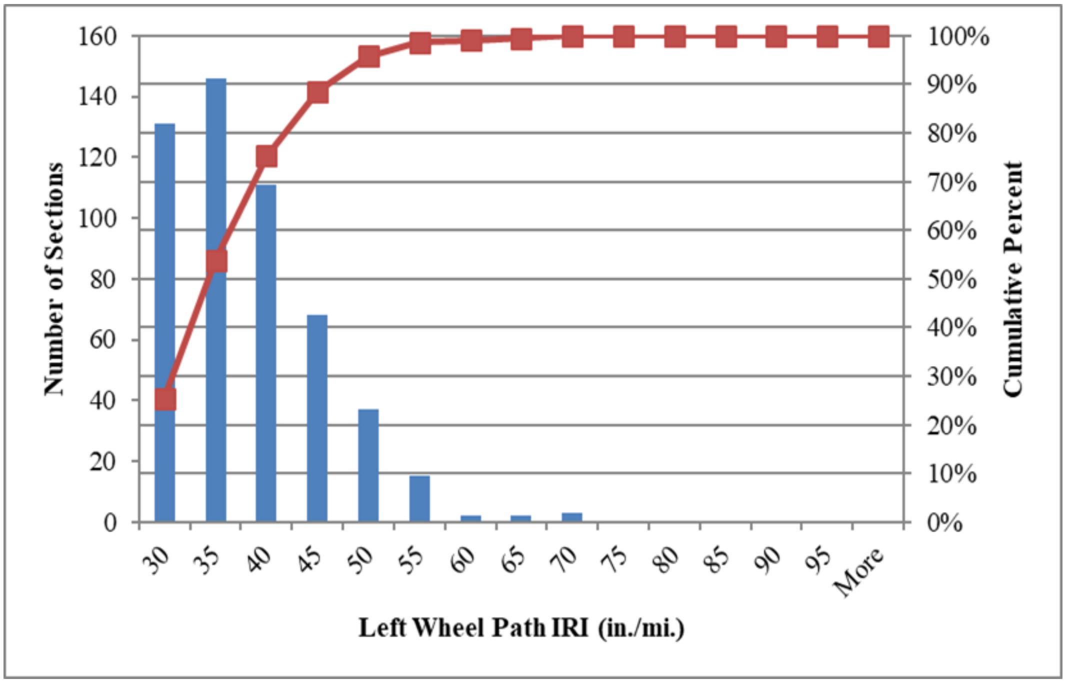

Figure 36. Left Wheel Path IRI for Multi-lift HMA (Group 7).

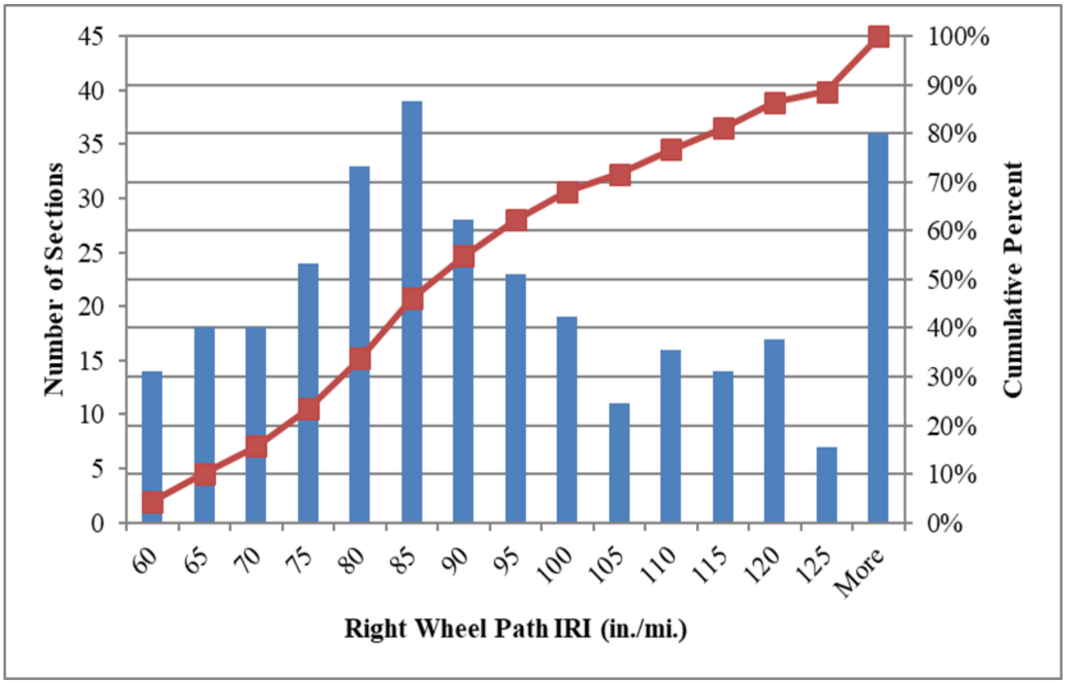

Figure 37. Right Wheel Path IRI for CRCP (Group 8).

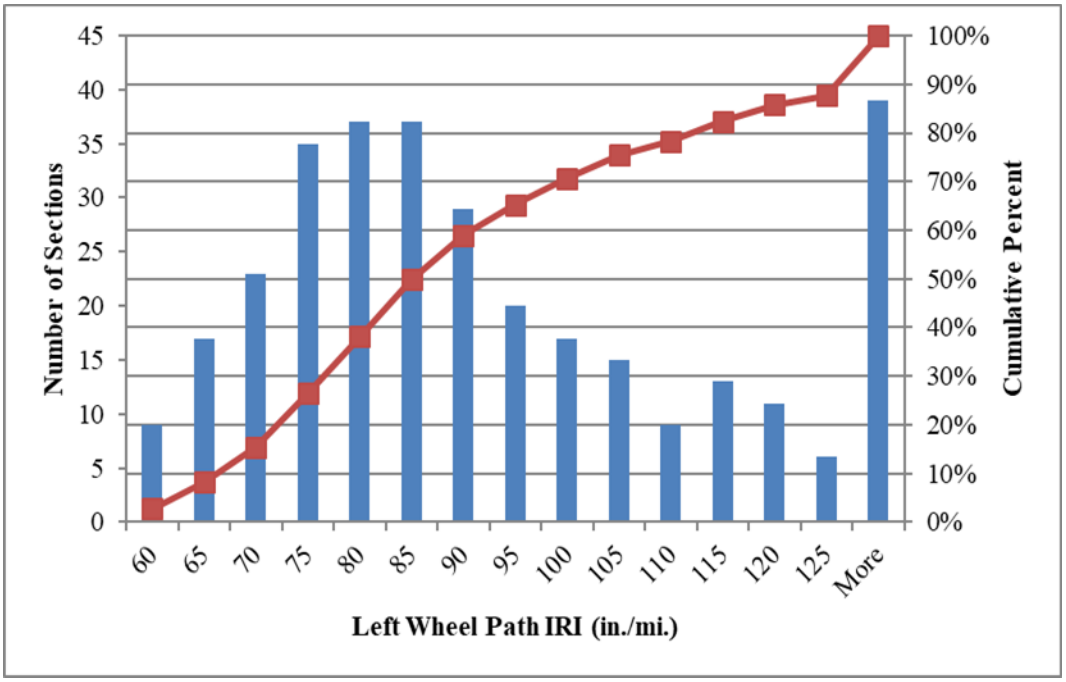

Figure 38. Left Wheel Path IRI for CRCP (Group 8).

APPENDIX C: REGRESSION EQUATION PLOTS FOR POST-CONSTRUCTION PREDICTION

The main body of this report includes the R^2 value for each of the regression equations. Table 9 shows the regression equations. The plots in this appendix (Figure 39 to Figure 45) show the data used to develop those regression equations.

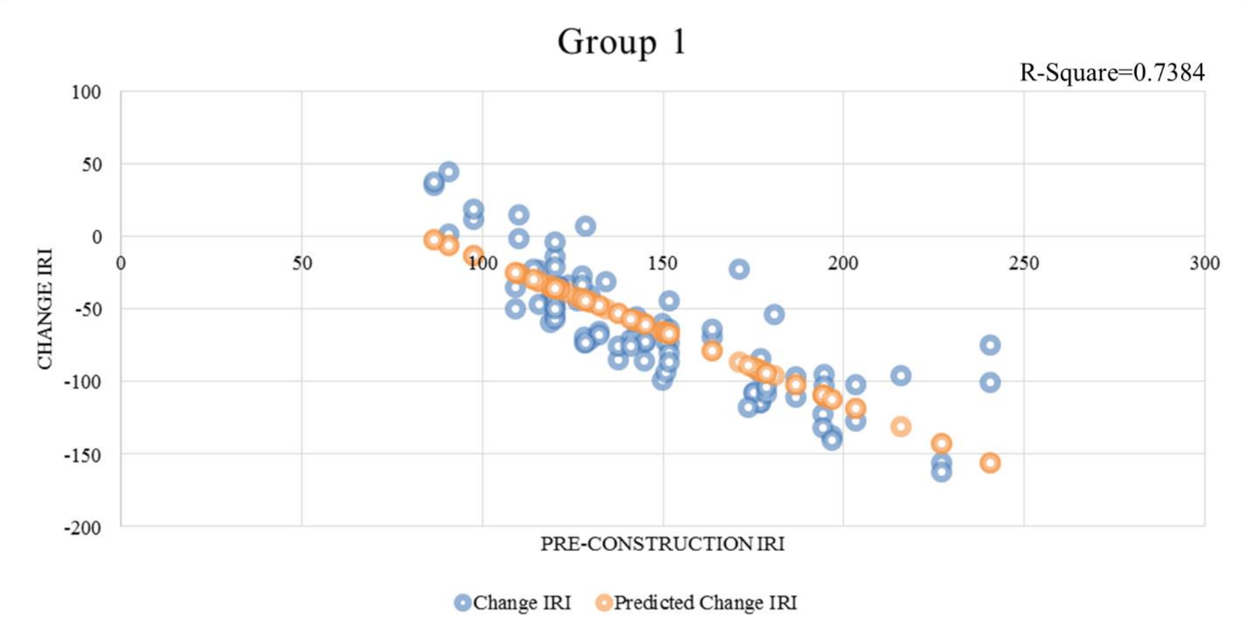

Figure 39. Group 1 Regression Equation Plot (Mill and Fill in Outside Lane of C&G).

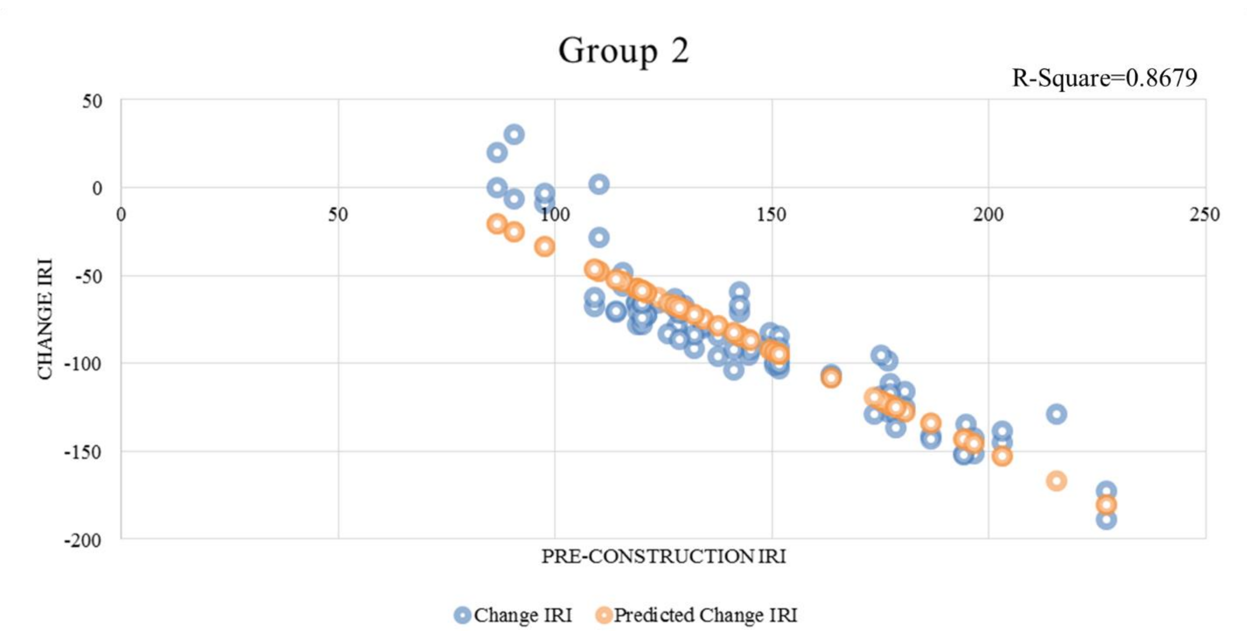

Figure 40. Group 2 Regression Equation Plot (Mill and Fill Not Constrained by Gutter).

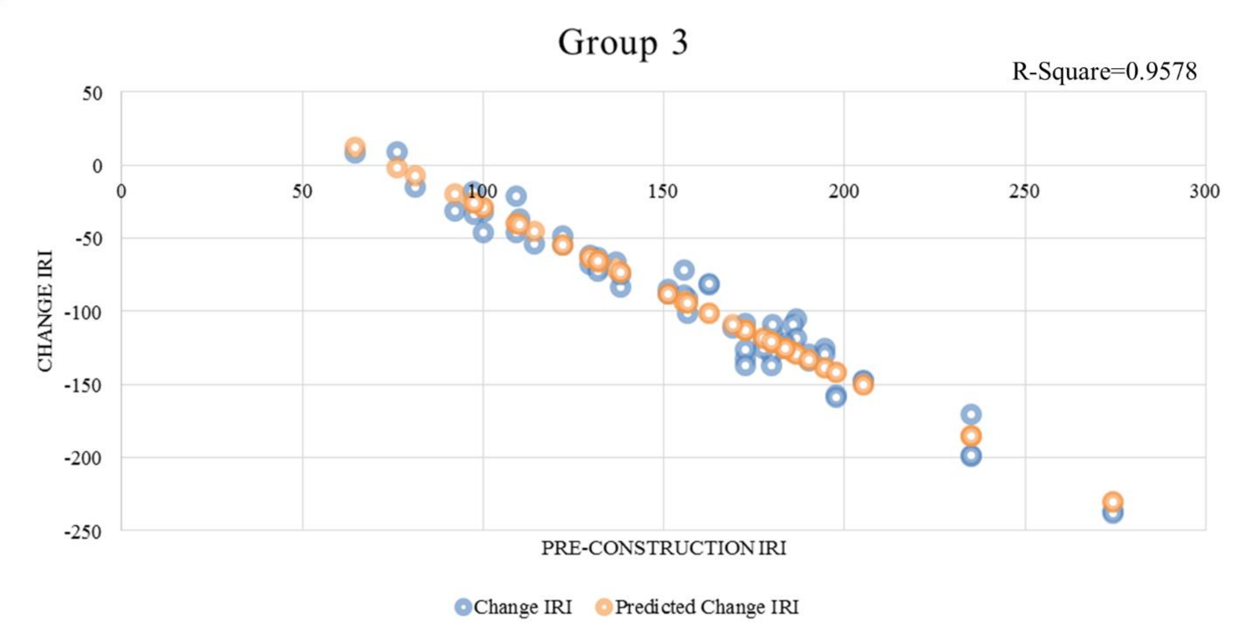

Figure 41. Group 3 Regression Equation Plot (Scarify with Overlay Projects Greater than or Equal to 1.5 in.).

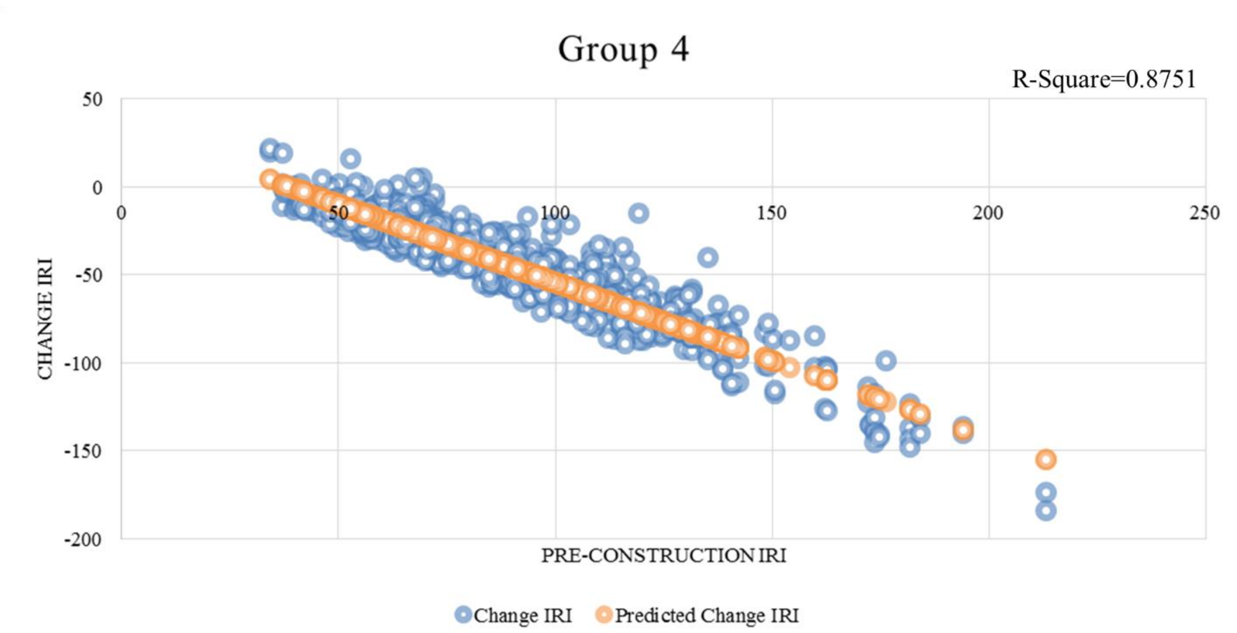

Figure 42. Group 4 Regression Equation Plot (Overlay Greater than or Equal to 1.5 in.).

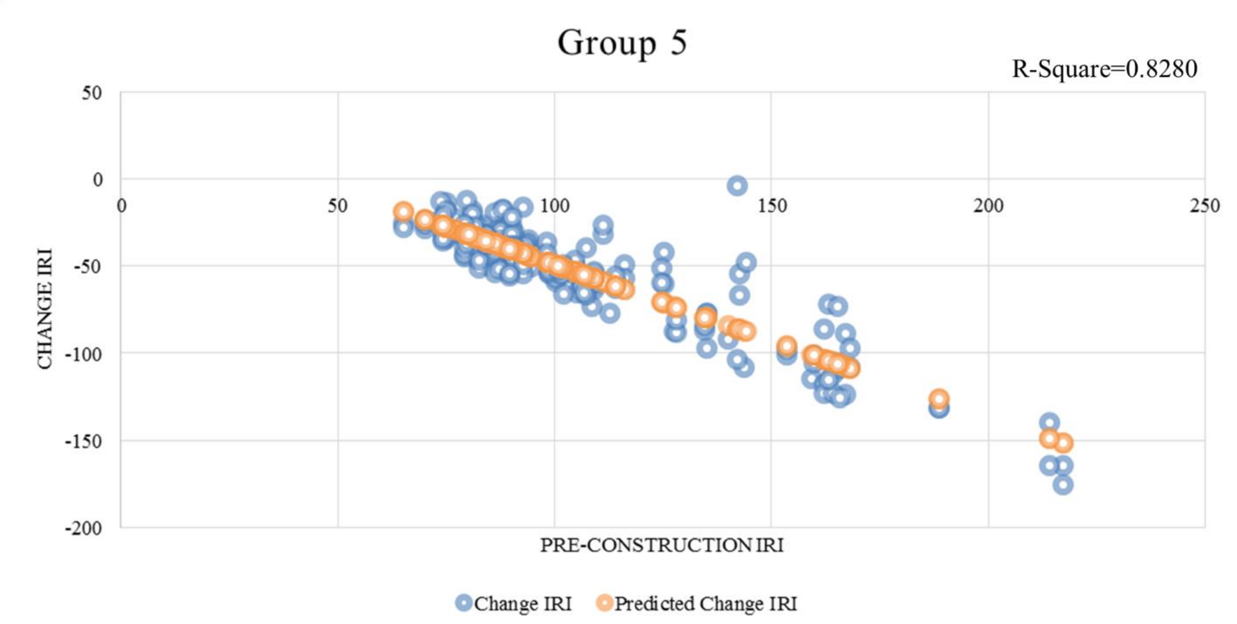

Figure 43. Group 5 Regression Equation Plot (Mill and Overlay Greater than or Equal to 1.5 in.).

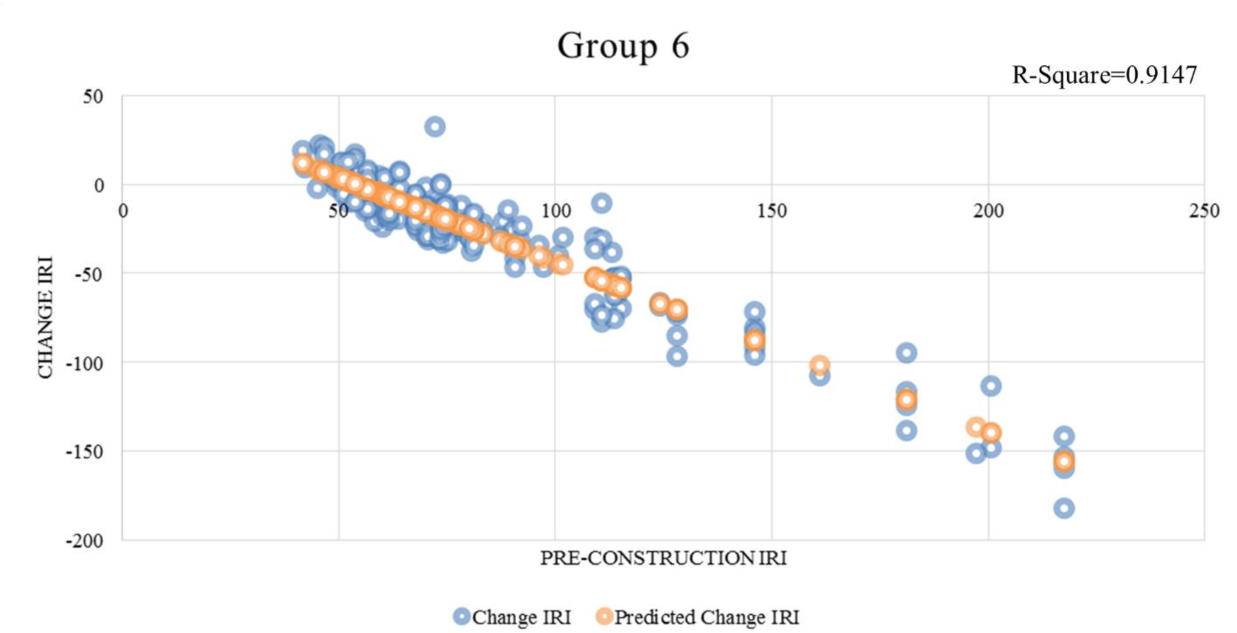

Figure 44. Group 6 Regression Equation Plot (Overlay Less than 1.5 in.).

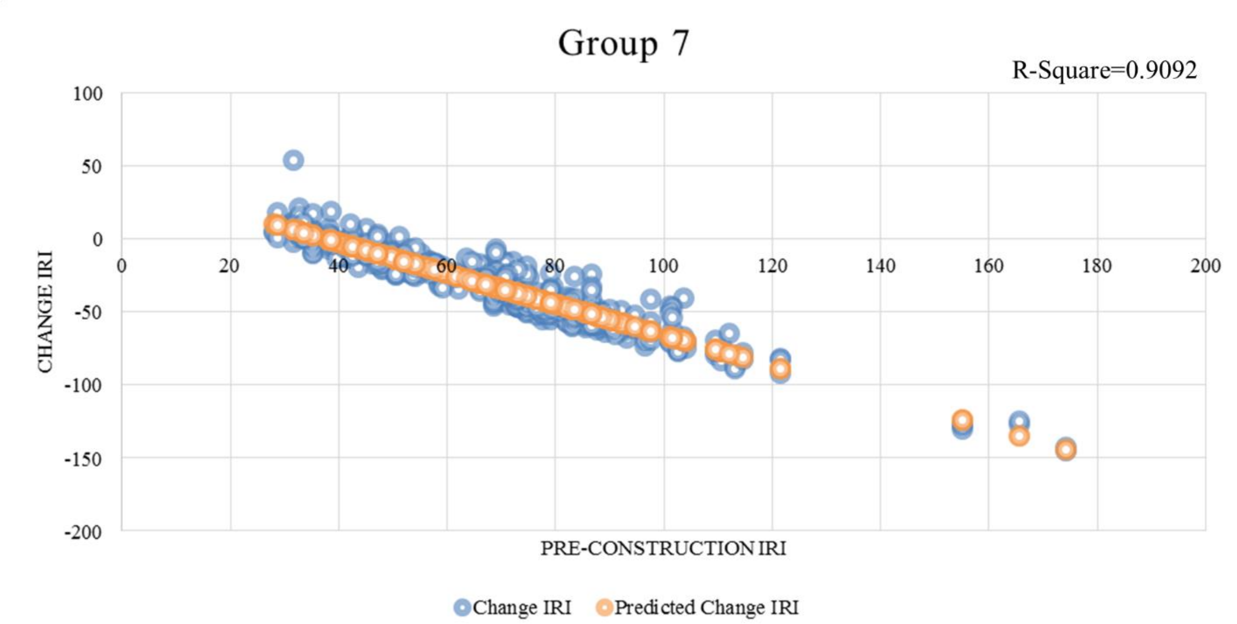

Figure 45. Group 7 Regression Equation Plot (Multi-lift HMA).

APPENDIX D: PROPOSED BONUS/PENALTY STRUCTURE CURVES

In the body of the report, Table 13 presents equations for each work group's pay structure. The graphs within this appendix (Figure 46 to Figure 53) illustrate this pay structure and compare them to the cumulative distribution curves for each work type.

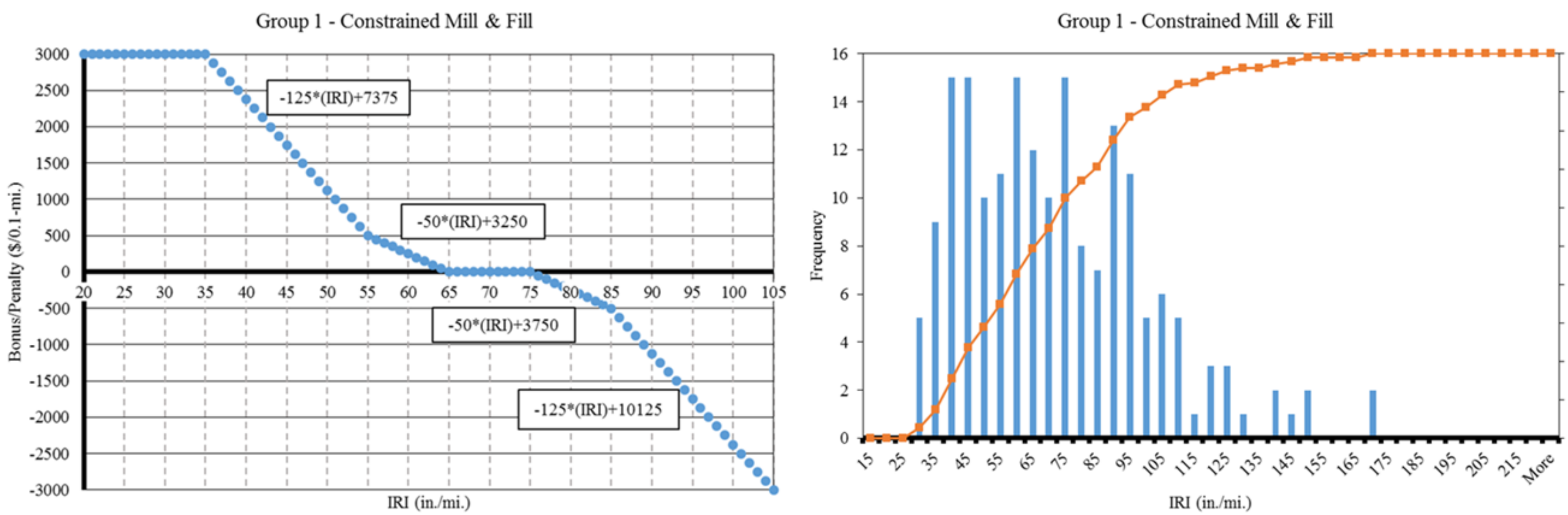

Figure 46. Group 1 Proposed Pay Structure Curve (Mill and Fill in Outside Lane of C&G).

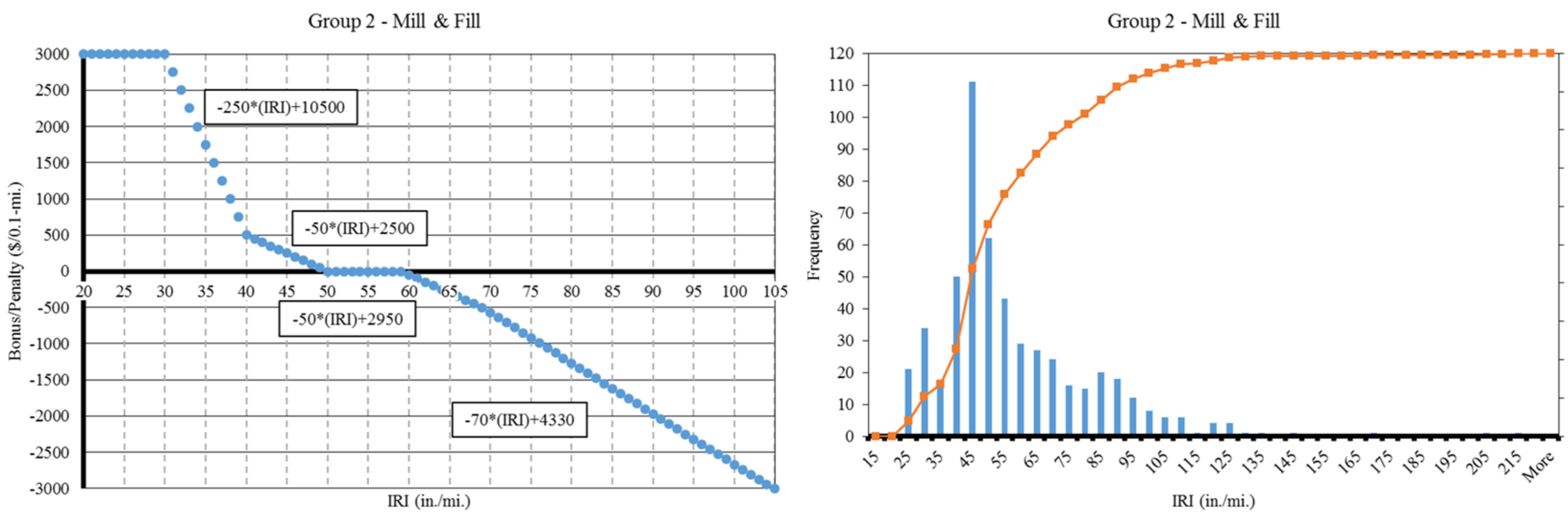

Figure 47. Group 2 Proposed Pay Structure Curve (Mill and Fill Not Constrained by Gutter).

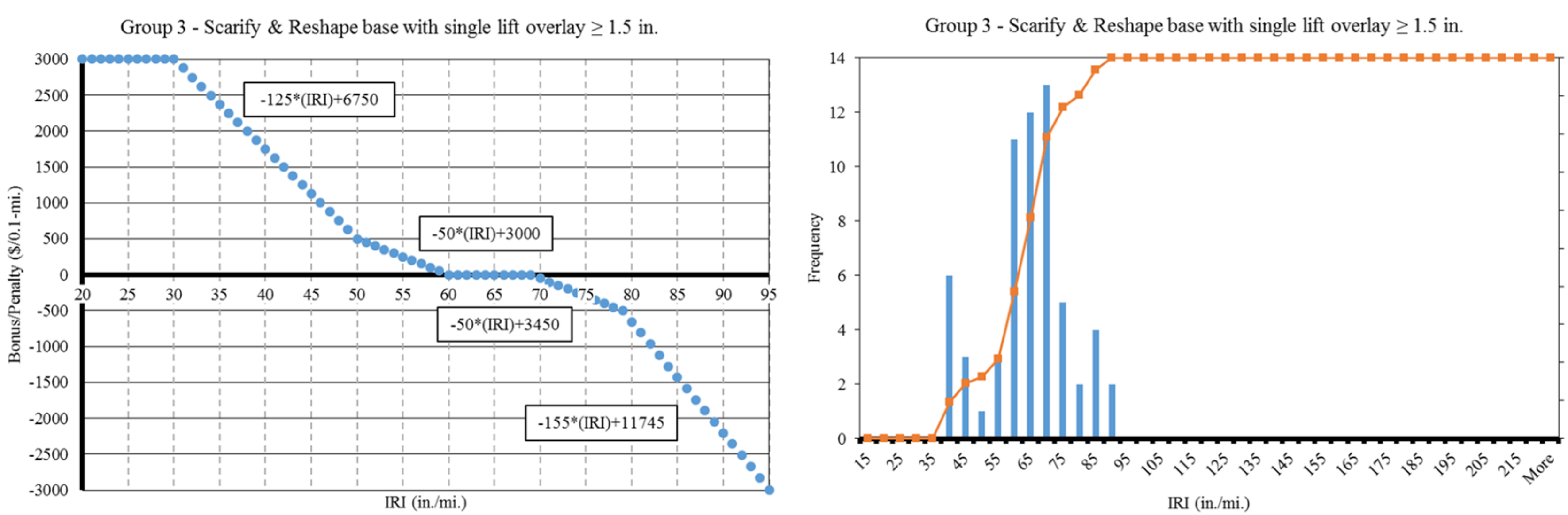

Figure 48. Group 3 Proposed Pay Structure Curve (Scarify with Overlay Projects Greater than or Equal to 1.5 in.).

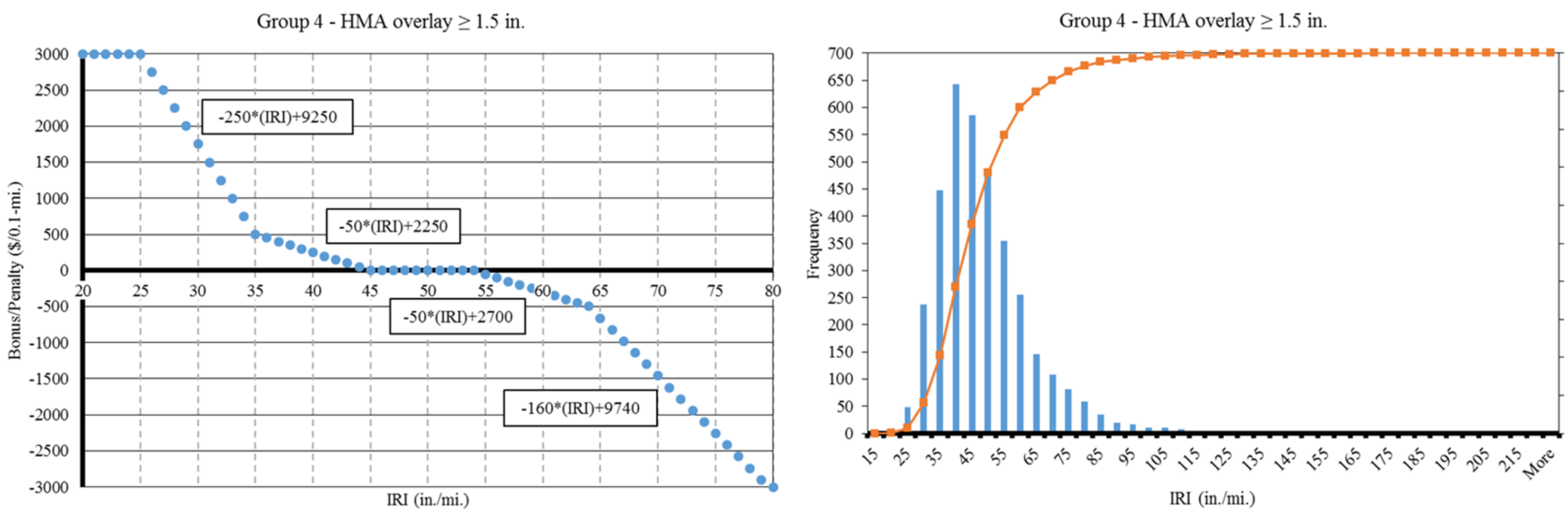

Figure 49. Group 4 Proposed Pay Structure Curve (Overlay Greater than or Equal to 1.5 in.).

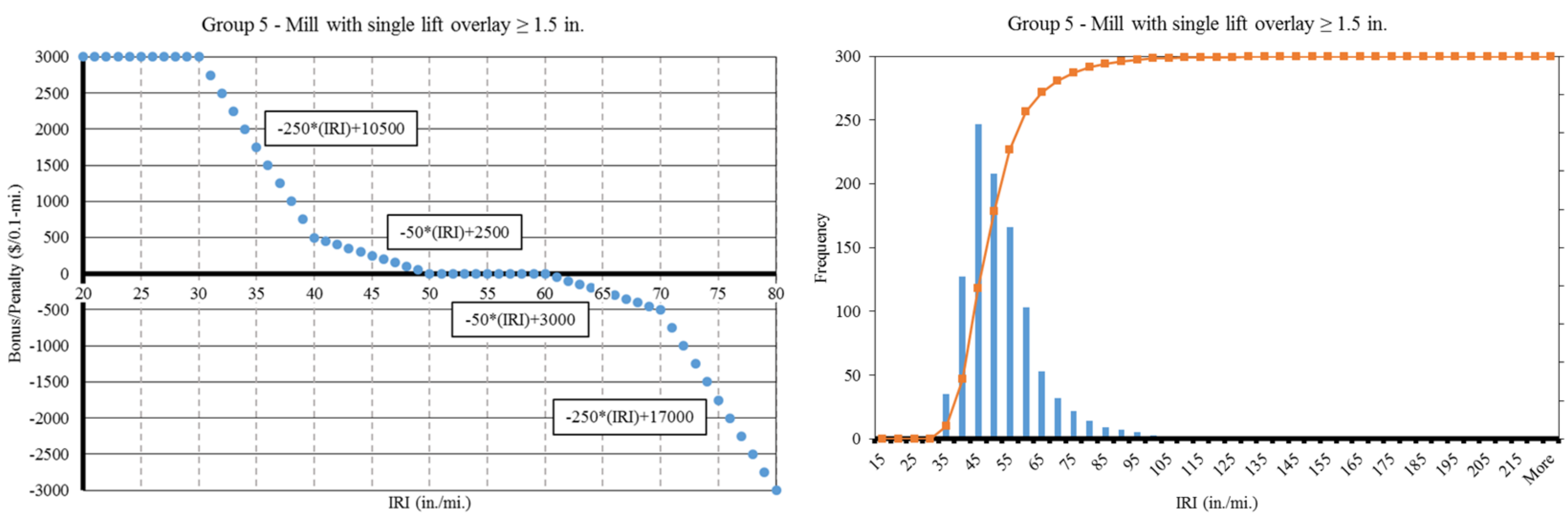

Figure 50. Group 5 Proposed Pay Structure Curve (Mill and Overlay Greater than or Equal to 1.5 in.).

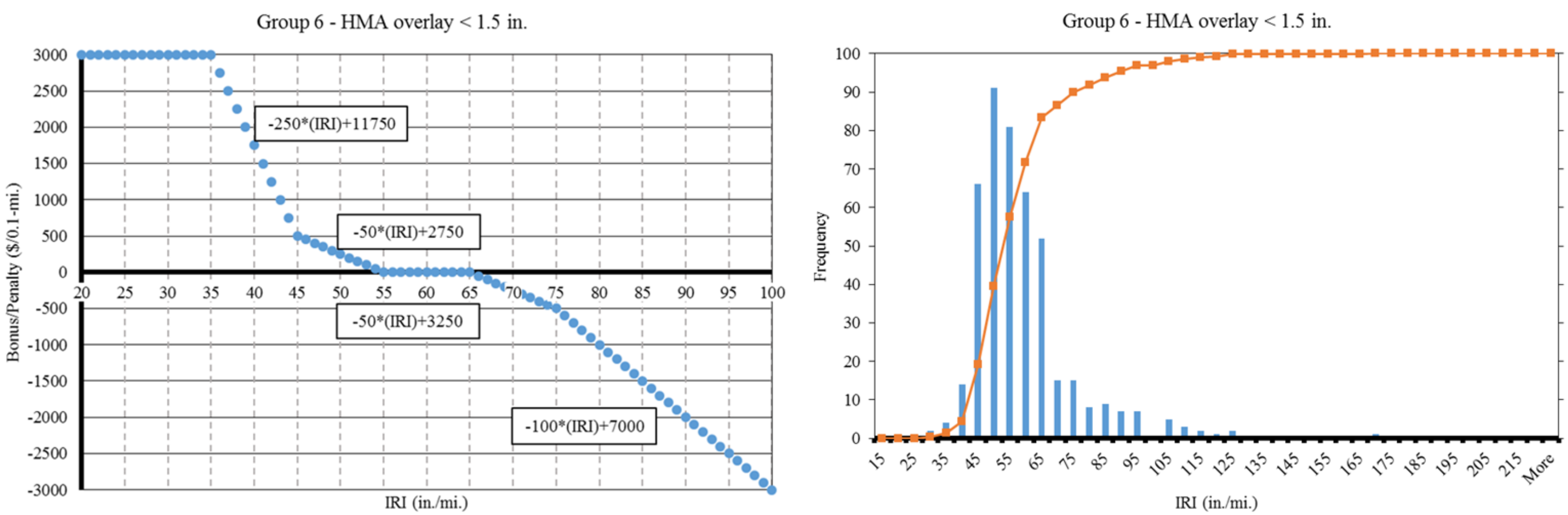

Figure 51. Group 6 Proposed Pay Structure Curve (Overlay Less than 1.5 in.).

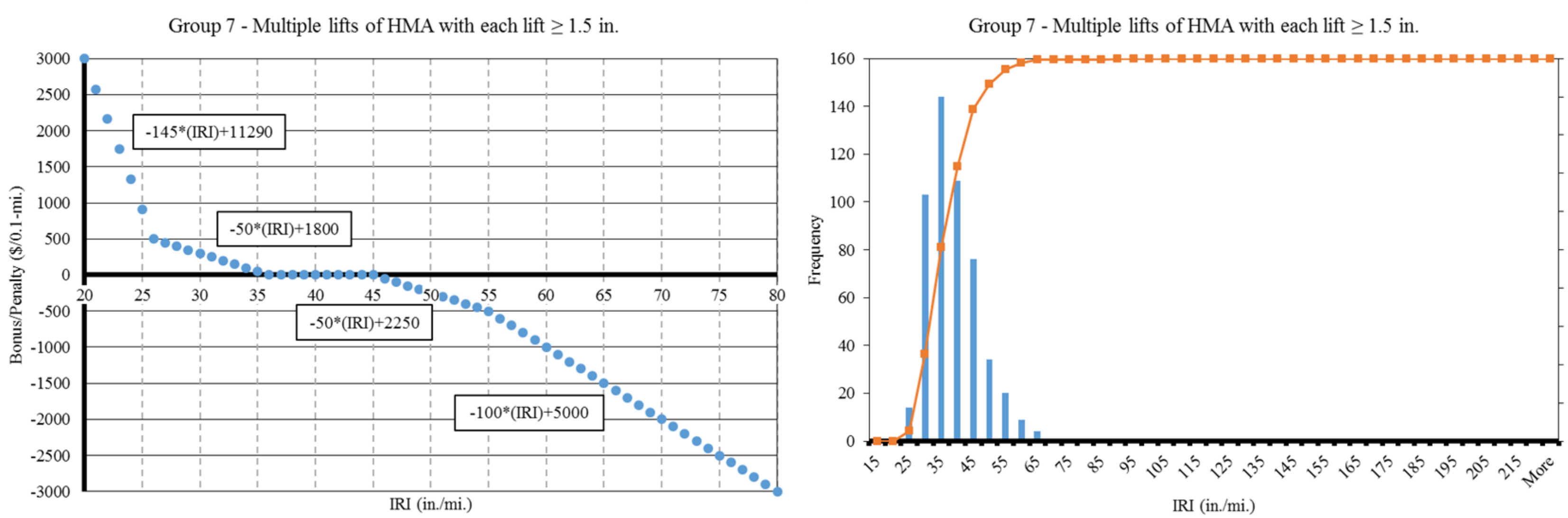

Figure 52. Group 7 Proposed Pay Structure Curve (Multi-lift HMA).

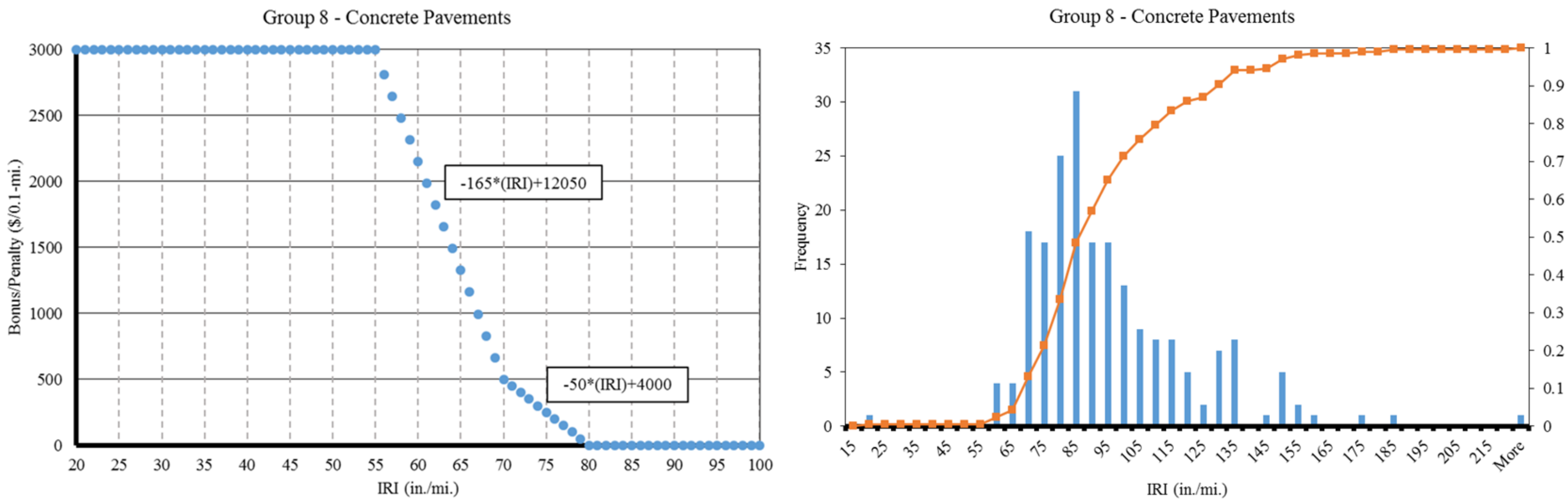

Figure 53. Group 8 Proposed Pay Structure Curve (CRCP).