# AID Project Summary Report for Intelligent Compaction

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Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

in cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

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**AID Project Summary Report for Intelligent Compaction**

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**16. Abstract**

This study reviews data from five roadway construction projects on which intelligent compaction (IC) techniques were used to achieve the more uniform compaction of road-building materials. Kentucky Transportation Center (KTC) researchers looked at IC data collected from these projects — resulting in the production of eight analyzable data sets — to determine whether they complied with the special construction note included in contract documents. The report also compares the intelligent compaction measurement value (ICMV) collected on each project to traditional laboratory results. Researchers used Veta software to analyze geospatial data collected from IC machines during construction work. Of the data sets, three indicated the required minimum coverage pass count had been achieved, although these did not attain the required minimum coverage for ICMV. Three other data sets achieved minimum ICMV coverage, while the final two data sets did not reach minimum coverage for either metric. Regression analysis found no meaningful relationship between density and ICMV. Attention is also paid to challenges which arose during the review of IC data and feedback received from contractors about the use of IC. Contractors appreciate that IC is able to transmit real-time data to operators and provides access to the mat temperature, however they observed inconsistencies with the ICMV for mill/fill projects and on new construction. These inconsistencies are the product of several factors, including cuts, fills, soil types, and the amount of water in the roller. A special construction note with instructions for using IC on Federal-aid projects is included as well. It specifies materials and equipment requirements, contractor responsibilities, construction methods, payment, and performance measures.

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# Executive Summary

The Federal Highway Administration (FHWA) awarded the Kentucky Transportation Cabinet (KYTC) an AID Demonstration Project to accelerate the adoption and implementation of intelligent compaction (IC) on Federal-aid construction projects in the state. For this study, Kentucky Transportation Center (KTC) researchers reviewed data from five roadway construction projects that used intelligent compaction (IC) techniques to achieve the more uniform compaction of road-building materials. This report also compares the intelligent compaction measurement value (ICMV) collected on each project to traditional laboratory results, summarizes challenges that arose during the review of IC data, and presents comments from contractors on the use of IC. Researchers used Veta software to analyze geospatial data collected from IC machines during construction work.

Of the data sets evaluated, three indicated the required minimum coverage pass count had been achieved, although these did not attain the required minimum coverage for ICMV. Three other data sets achieved minimum ICMV coverage, while the final two data sets failed to reach the minimum coverage for either metric. Based on available information, regression analysis found no meaningful relationship between density and ICMV. Researchers encountered several problems during analysis, which should be corrected before future analysis of IC data. Consistent IC data collection methods should be employed, and up-to-date software used for analysis. When Veta software is used, IC data collection should be performed in a geographic coordinate system rather than a state plane coordinate system. Because the IMCV can vary for each roller, information on the number of IC rollers used and the makes and models should be available. When IC data are intended for quality assurance, a designated owner representative needs to be assigned to collect and monitor all IC data in the state.

Contractors observed that a primary benefit of IC lies in its ability to convey real-time data to operators. The IC interface is easy to set up and operate, while the display is easy to see. They indicated that having access to the mat temperature is beneficial for confirming that compaction is performed within optimal range. Contractors, however, noted inconsistencies with the ICMV for both mill/fill projects and new construction. Inconsistencies are the product of many factors: cuts, fills, soil types, and the amount of water in the roller. Contractors identified several other challenging issues: no real-time feedback from IC data, slow data transmission, and unreliable modems that can result in significant downtime. IC rollers are also twice as expensive as traditional rollers, and the extra cost needs to be incentivized.

Appendix F contains the special construction note with instructions for using IC on Federal-aid projects. The note specifies materials and equipment requirements, contractor responsibilities, construction methods, payment, and performance measures.

# Introduction

FHWA's Every Day Counts 2 initiative promoted the use of Intelligent Compaction (IC) as an innovative method to achieve more uniform compaction of road-building materials. Subsequently, FHWA awarded the Kentucky Transportation Cabinet (KYTC) an AID Demonstration Project to accelerate the adoption and implementation of IC on Federal-aid construction projects in the state. As part of this project, KYTC prepared a special construction note that contains instructions for using IC on these Federal-aid projects. This note specifies materials and equipment requirements, contractor responsibilities, construction methods, payment, and performance measures required for IC. Appendix F contains the special note for the Clark County project analyzed below.

This report reviews IC data collected from several projects to determine whether the construction phase complied with the special note included in contract documents. This report also compares the intelligent compaction measurement value (ICMV) collected on each project to traditional laboratory results, summarizes challenges that arose during the review of IC data, and presents comments from contractors regarding the use of IC.

Five projects were evaluated, with four of the five being mill and fill projects where 1.5 inches of the existing surface was milled away and replaced with a 1.5-inch surface course. The fifth project was a widening project where multiple base courses were placed along with a surface course. Table 1 summarizes information about each project.

**Table 1** Selected Projects

| County | CID | Route | MP to MP | Type | Base | Surface |
|---|---|---|---|---|---|---|
| Clark | 161060 | PW-9000 | 0.00 to 5.311 | mill/fill | n/a | 1.5 inch |
| Pike | 161046 | US-23 | 29.5 to 32.78 | mill/fill | n/a | 1.5 inch |
| Rockcastle | 161270 | I-75 | 64.5 to 69.0 | widening | 11.5 inch | 1.5 inch |
| Adair | 161261 | PW-9008 | 36.159 to 43.020 | mill/fill | n/a | 1.5 inch |
| Warren | 161052 | I-65 | 25.2 to 35.26 | mill/fill | n/a | 1.5 inch |

# Methodology

The available IC and density data were measured for each project. Project data sets were reviewed to determine which could be evaluated in Veta, software initially developed jointly by FHWA and the Minnesota Department of Transportation to analyze geospatial data from IC machines. Before importing data files into Veta, the coordinate system used for each project had to be known. If the roller type varied, asphalt type/course changed, or target IC values changed, separate analyses were performed. For one project, the Veta project file was the only file given to researchers for analytical purposes; each file had to be extracted from Veta prior to review. Individual IC data files were evaluated for the remainder of the projects as those files were provided.

Analysis employed Veta version 5.2.57. For each project, a new Veta project was created and the appropriate IC data files and density data were added to the project file. The construction special note indicates that a minimum of 80% coverage is required for the target pass count and a minimum of 75% coverage is required for the target ICMV. Based on these limits, analysis in Veta focused on determining the final coverage percentages for the target pass counts and target ICMVs. Veta was used to undertake least squares linear regression on density–ICMV relationships (with density as the independent variable), and associated $R^2$ values were recorded.

If the density location referencing for a project matched the IC data location referencing, the densities were copied into the *Spot Tests* portion of the Veta for analysis. However, some projects referenced density locations by mile point and lane number. For these projects, density locations were mapped in ArcGIS based on linear referencing, which uses a mile point measure to locate the core along a route. An offset was applied to situate the core in the appropriate lane. Core locations were then projected into the appropriate coordinate system, and geometry fields calculated for the Northing and Easting of each core.

No contractor IC work plans were available for analysis and would have proved beneficial for determining the number of IC rollers used on a project as well as the type of IC measurement system employed, software used for data collection, and the roller pattern. IC data files contain embedded information on roller make and model, and these files assume the same roller was used across a project unless the model designation was changed.

Lastly, comments and feedback were solicited from contractors and industry members about their use of IC on highway projects. Questions focused on the equipment's ease of use, reliability, accuracy, and efficiency, but general opinions about the technology were encouraged as well. Contractor comments are discussed later in the report in the section titled "Contractor Perspective."

<div align="center">**Project Analysis**</div>

**Project 1 Clark Co. CID 161060**

IC data — provided in eight Microsoft Excel files — were imported into the Veta program for analysis. One of the eight files contained no data. For this project, the target thickness of the IC roller was set to 0.656 feet despite it being a mill with a 1.5-inch asphalt overlay. An Excel file provided surface densities and included the lot, sublot, core location (by Northing/Easting), and % solid density. These densities were imported into the Veta program. Locational information for the IC data and density data were in Kentucky State Plane Single Zone. Because the IC data were in a state plane coordinate system, mapping did not appear in the Veta program. IC data files included the target pass count and ICMV. Based on the defined targets, analysis indicated 90.15% coverage with a pass count of 2 or more and ICMV coverage of 44.80% at 50 or more. Thirty-seven (37) surface densities were provided but only 25 were used for comparisons with the ICMV mostly because the IC data for the first lot of asphalt was not provided for this analysis. Regression suggested a poor relationship between density and ICMV ($R^2 = 0.03$).

**Project 2 Pike Co CID 161046**

Analysis for this project attempted to leverage a Veta project file. The Veta program file indicated data were organized by lane, direction, and a designation of "F" and "R." It was assumed the "F" and "R" represented forward passes and reverse passes, respectively. All of the "R" files were removed from the Veta data set to confirm this assumption, however, the remaining data still contained reverse passes. Both forward and reverse directions consisted of a mix of static and vibratory compaction modes. Unlike the Clark County project, IC data lacked embedded target pass counts and an ICMV. Furthermore, no density information was made available for this project. Given the uncertainties inherent to the data and the lack of target values and density information, analysis for this project was not feasible.

**Project 3 Rockcastle Co CID 161270**

The supplied Veta project file could not be opened, while the individual IC data files were provided in Excel format. Ten IC data files were available — nine files for the first asphalt base lift and one file for the second asphalt base lift. Before loading files into Veta, the date format for each IC log entry was corrected by replacing the "/" symbol with the "-" symbol. Along with the problematic date format, the contractor used the Kentucky State Plane South Zone coordinate system. In this format, Veta could not display the mapping in the background and only showed the IC data, which made it difficult to confirm the location of IC data and provide reference to scale. The original density data were referenced by mile point and direction rather than using a coordinate system, which required conversion to Kentucky State Plane South Zone in order to compare the ICMV value and density. All densities were positioned in the middle of the inside lane as this is the section of roadway that was widened. After importing IC data into Veta and reviewing it, it became apparent that the second asphalt base lift did not cover the same extent of the first asphalt base lift. As a result, no meaningful analysis comparing the asphalt base core densities with the ICMV values could be performed, and no IC files were provided for the asphalt surface.

Analysis sought to determine coverage percentages based on target values embedded in the IC data files. Both the first and second base lift IC data files listed the target pass count and ICMV as being 2 and 50, respectively. Analysis showed the first base lift achieved a 79.76% coverage for pass counts greater than or equal to 2, while the coverage for an ICMV of 50 or more was 2.21%. The pass count coverage for the second base lift was 80.63% and the ICMV coverage was 2.44%. Coverages for target pass count and ICMV with the first and second base lift, where they overlapped, were 80.43% and 2.36%, respectively. Only three core densities were located along the section where the base lifts overlapped. Least squares regression found a modest relationship between density and ICMV ($R^2 = 0.35$).

**Project 4 Adair Co CID 161261**

Fourteen Excel files housed the IC data for this project. Examining the IC data files revealed that two different rollers (CB54XW and CB54JM) were used for compaction. As such, two separate Veta project files were set up for analysis. Because the density data omitted location information, using regression to evaluate the density–ICMV relationship was not possible. As the IC data's location information was in Kentucky State Plane Single Zone, the Veta program could not display the background mapping. Each IC data file contained the target pass count and ICMV. The CB54XW roller used a target pass count of 5 and had a target ICMV of 50. Analysis based on the parameters from the embedded IC settings found 9.46% coverage for the pass count and 98.67% coverage for the target ICMV. The CB54JM roller was set to a target pass count of 4 with a target ICMV of 50. Analysis indicated the target pass count coverage was 30.55% and the target ICMV coverage was 96.96% (target thickness set to 0.656).

**Project 5 Warren Co CID 161052**

The IC data for this project were stored in 19 Excel files. Reviewing the individual IC data files uncovered several issues. First, three of the files could not be opened in their entirety due to Excel's row limitation. This inhibited efforts to quickly review the IC data for anomalies or changes in the IC setting such as the target pass count settings and target ICMV. Second, the target ICMV in two files was 25 rather than 39, although the target pass count of 4 and the roller name were identical across files. In addition to the target ICMV change, it appeared that asphalt base was applied to the on/off ramps, however it was not clear if the IC data contained any base compaction information. The IC data files showed the target thickness was set to 0.128 ft. Based on the other projects analyzed here, the target thickness cannot be used to determine the difference between asphalt lift types. Accordingly, the IC data that contained on/off ramp data were removed from the Veta data set, restricting focus to the mainline roadway's surface compaction. The locations of the surface densities were referenced by mile point, direction, and lane number. Mile points were converted to Kentucky State Plane Single Zone to match the IC data's location format. The offsets were identified by the lane number, with L1, L2, and L3 being identified as the slow lane, middle lane, and fast lane, respectively. Lane designations were assumed. Likewise, locations were assumed to be situated in the middle of a lane. Densities were added to the Veta project and included in the analysis.

Two Veta project files were set up to analyze the IC data with different target ICMVs. With the pass count set to 4 or greater and ICMV set to 39 or greater, the pass count coverage was 78.59% and the ICMV coverage 72.97%. The $R^2$ for the density–ICMV regression was 0.00. The coverages for the other data set were 63.11% for a target pass count of 4 or more and 80.32% for an ICMV of 25 or more, yielding a more robust $R^2$ value of 0.19 for the density–ICMV regression.

# Analysis Summary

Table 2 presents the analytical results for each construction project. Data for several projects required separate analysis because either a different roller was used, target IC values changed, or different asphalt courses were compacted.

Analysis of the four projects employed eight data sets. A ninth data set was created but target IC values were not available for the analysis. This project used Hamm equipment while the other eight used Caterpillar equipment. Three of the eight data sets had acceptable target pass count coverage, but those three failed to achieve the minimum acceptance coverage for the ICMV. The three data sets which attained the threshold minimum coverage for target ICMV failed on the acceptance coverage for target pass count. Interestingly, the target ICMV for Caterpillar equipment was set to 50 for six of the eight data sets.

**Table 2** Target IC Values and Acceptance

| Project | Target Pass Count | | | Target ICMV | | | Roller | |
|---|---|---|---|---|---|---|---|---|
| | Value | Final Coverage (%) | Acceptance | Value | Final Coverage (%) | Acceptance | Make | Model |
| 1 | 2 | 90.15 | Passed | 50 | 44.80 | Failed | Caterpillar | CB54 |
| 2 | n/a- | - | - | n/a | - | - | Hamm | - |
| 3 | 2 | 80.43 | Passed | 50 | 2.36 | Failed | Caterpillar | CB54XW |
| 3a | 2 | 79.76 | Failed | 50 | 2.21 | Failed | Caterpillar | CB54XW |
| 3b | 2 | 80.63 | Passed | 50 | 2.44 | Failed | Caterpillar | CB54XW |
| 4a | 5 | 9.46 | Failed | 50 | 98.67 | Passed | Caterpillar | CB54XW |
| 4b | 4 | 30.55 | Failed | 50 | 96.96 | Passed | Caterpillar | CB54JM |
| 5a | 4 | 78.59 | Failed | 39 | 72.97 | Failed | Caterpillar | CB64 |
| 5b | 4 | 63.11 | Failed | 25 | 80.32 | Passed | Caterpillar | CB64 |

Least squares linear regression performed in Veta identified weak or no relationships between the density and target ICMV (Table 3). In fact, as the number of density readings increased the $R^2$ value trended toward zero.

**Table 3** Density/ICMV Correlation

| Project | No. Density Readings | Average Density (%) | Target ICMV | R Squared | Comments |
|---|---|---|---|---|---|
| 1 | 37 | 91.4 | 50 | 0.03 | As density increased the ICMV decreased (see Figure 3 in append.) |
| 2 | - | - | - | - | No density data provided |
| 3 | 3 | 92.8 | 50 | 0.35 | Only three cores densities within the area |
| 3a | - | - | 50 | - | Density for individual lifts not provided |
| 3b | - | - | 50 | - | Density for individual lifts not provided |

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| 4a | 77 | 92.4 | 50 | - | Density data did not contain location information |
|----|------|--------|----|------|--------------------------------------------------|
| 4b | See 4r1 | See 4r1 | 50 | - | Density data did not contain location information |
| 5a | 78 | 93.3 | 39 | 0.00 | |
| 5b | 7 | 94.1 | 25 | 0.19 | Only seven core densities within the area |

To achieve a 1.00 to 1.05 pay value on asphalt the target lane density for contractors is between 92% and 96%. For three of the four data sets, the average density exceeded the 1.00 pay value, but the pass count acceptance failed for two of the data sets and the ICMV acceptance failed on three. This suggests that either the targets embedded in the IC data files used for the acceptance analysis were incorrect and/or considerable variability exists in the ICMV.

**Table 4** IC Summary Statistics

| Project | Density | | Pass Count | | | ICMV | | |
|---------|---------|------|------------|-----|---------|-------|-------|---------|
| | Avg. (%) | SD | Avg. | SD | Accept. | Avg. | SD | Accept. |
| 1 | 91.4 | 2.14 | 3 | 2 | Passed | 53.11 | 25.63 | Failed |
| 3 | 92.8 | 0.47 | 7 | 5 | Passed | 26.49 | 10.95 | Failed |
| 5a | 93.3 | 1.72 | 6 | 3 | Failed | 48.75 | 17.95 | Failed |
| 5b | 94.1 | 0.82 | 5 | 3 | Failed | 40.18 | 16.00 | Passed |

Project 5a — Warren County, with a target pass count of 4 and ICMV of 39 — failed to achieve both the target pass count and ICMV acceptance coverages even though the average density, out of 78 readings, was above the 1.00 pay value for densities. However, the standard deviation was within the 0.95 to 1.00 pay value. The target pass count for this project was 4 but the average pass count was 6 with a standard deviation of 3, indicating that within one standard deviation there is coverage failure. The target ICMV was 39 and the average was 48.75 with a standard deviation of 17.95, again demonstrating coverage failure within one standard deviation of the average. In fact, the average percent difference between the standard deviation of the pass count and the average pass count was approximately 50% and 80% for the ICVM, signaling variability within the IC data.

# Other Observations

**Using Veta**
- The supplied Veta project files would not open in Veta, indicating a possible bug with the software or compatibility issues that emerge when trying to open older project files with a newer version of the software.
- If IC data are not collected in a geographic coordinate system, background mapping will not appear in Veta, and the user cannot make linear measurements in the program. One benefit of using IC data is being able to quickly see the extent and magnitude of the compaction effort. However, when mapping cannot be displayed in conjunction with the IC results there is no frame of reference for actual locations, nor are measurements possible.
- When collecting density data to compare with IC data, all must be collected in the same geographic coordinate system as the IC data as this facilitates comparisons between densities and ICMV.
- Separate IC data files should be required for each structure type (i.e., base lift 1, base lift 2, surface) and named accordingly so they are easily identifiable without users having to open the data set to figure out their purpose.
- IC calibration is roller specific. In light of this, separate IC data files should be available for each roller used on a project.
- Veta software does not save its analysis. After performing an analysis in Veta and saving a project, analysis has to be redone to see the results. Analysis can be saved as a PDF report or exported to Excel.
- IC data exported from Veta could not be recognized by the Veta program for import.

**IC Data**
- Caterpillar IC data contained the target IC values, whereas Hamm IC data did not contain the target IC data needed for an analysis.
- It is not clear if the test sections were part of the IC data provided. It would be beneficial if the test strip compaction curve could be embedded into the project file, or test sections need to be named accordingly for easy identification and analysis.
- Three mill and fill projects had a target thickness of 0.656 feet in the IC data files.

# Contractor Perspective

Contractors were asked about their use of IC on highway projects and to provide their opinions about the technology. Several conclusions emerged from a review of their responses. First, a primary benefit of IC is conveying real-time data to operators. Being able to see the pass count and coverage helps reduce human error. Second, having access to the mat temperature is beneficial as well in that it lets workers confirm that compaction is performed within optimal range. The IC interface is easy to set up and operate, while the display is easy to see during daytime and nighttime hours and the color-coding of the passes enables a quick reference while rolling. Setting up the GPS through an RTK network is more convenient than setting up separate base stations.

Contractors noted inconsistencies with the ICMV for both mill/fill projects and new construction projects. These inconsistencies are influenced by many factors, including cuts, fills, soil types, and even the amount of water in the roller. Although real-time information is valuable, no feedback from the IC data was sent. Contractors also noted that sending data is slow, which causes a backlog. The Trimble SNM 940 modem is unreliable and results in significant downtime and requires the use of personal hotspots for connectivity. Lastly, IC rollers are twice as expensive as traditional rollers and the extra cost needs to be incentivized.

## Summary and Recommendations

This report discussed the use of IC on five highway projects. IC data were reviewed prior to being imported into Veta to determine which data for each project could be analyzed together — IC data are specific to pavement type, thickness, and roller. Densities for each project were obtained from the state's asphalt mix acceptance workbook (AMAW) and entered into Veta. Coverage analyses in Veta were based on target pass counts and ICMVs embedded in the IC data files, and the acceptance limits on a minimum 80% coverage for the target pass count and 75% coverage for the target ICMV (as per the special note). Each analysis was performed using the default radius of 3.28 feet.

Following the data review, nine data sets were generated across the five highway projects and evaluated for final pass count coverage, final ICMV coverage, and the relationship between densities and ICMV. One data set could not be analyzed because the target pass count and target ICMV were unavailable. Three of the eight data sets (Projects 1, 3, and 3b) achieved the required minimum coverage for pass count, however, those projects failed to attain the minimum required coverage for the ICMV. Three of the eight data sets (Projects 4a, 4b, and 5b) achieved the ICMV minimum coverage, while two datasets failed on both acceptance metrics. Six of the eight data sets used the same target ICMV of 50, which may indicate the target ICMV was selected arbitrarily or ignored.

Based on the information available for this report, regression analysis found no meaningful relationship between density and ICMV. Regression performed using two data sets, each of which had more than 70 density values to compare to the ICMV, returned $R^2$ values of 0.03 and 0.00. Two other data sets had 3 and 7 density results; these had improved $R^2$ values of 0.19 and 0.35, respectively. But the low number of density observations lessens the statistical robustness of these regressions.

Several problems were encountered during analysis and it strongly recommended these problems be corrected prior to any future analysis or evaluation of IC data. Nine recommendations for resolving these challenges are described below.

1. There should be a consistent way to collect, name, and store IC data. Separate IC data files should be created for each roller, asphalt type, and asphalt thickness. IC data file names must be standardized so users can easily identify the purpose of IC data.
2. Target pass counts and the target ICMV established during test strip paving should be logged and made available for analysis.
3. Contractor work plans (as required by the special note) which provide details on the number of IC rollers used, make and models, and other information need to be available.
4. The ICMV can vary for each roller. If there is more than one of the same model roller on a job, each should be logged in the IC data file — not just by the model number of the IC roller.
5. All contractors using IC rollers should ensure their IC equipment is updated and using the latest software to ensure IC data are compatible with the most current version of Veta.
6. All IC data collection should be performed using a geographic coordinate system rather than state plane coordinates if there are plans to use Veta's mapping feature.
7. All density locations should be collected in the same coordinate system as the IC data.
8. Target thicknesses must reflect the actual target lift thickness of the material being compacted.
9. If IC data are intended for use as a quality assurance tool, a designated owner representative should be assigned to collect and monitor all IC data in the state.
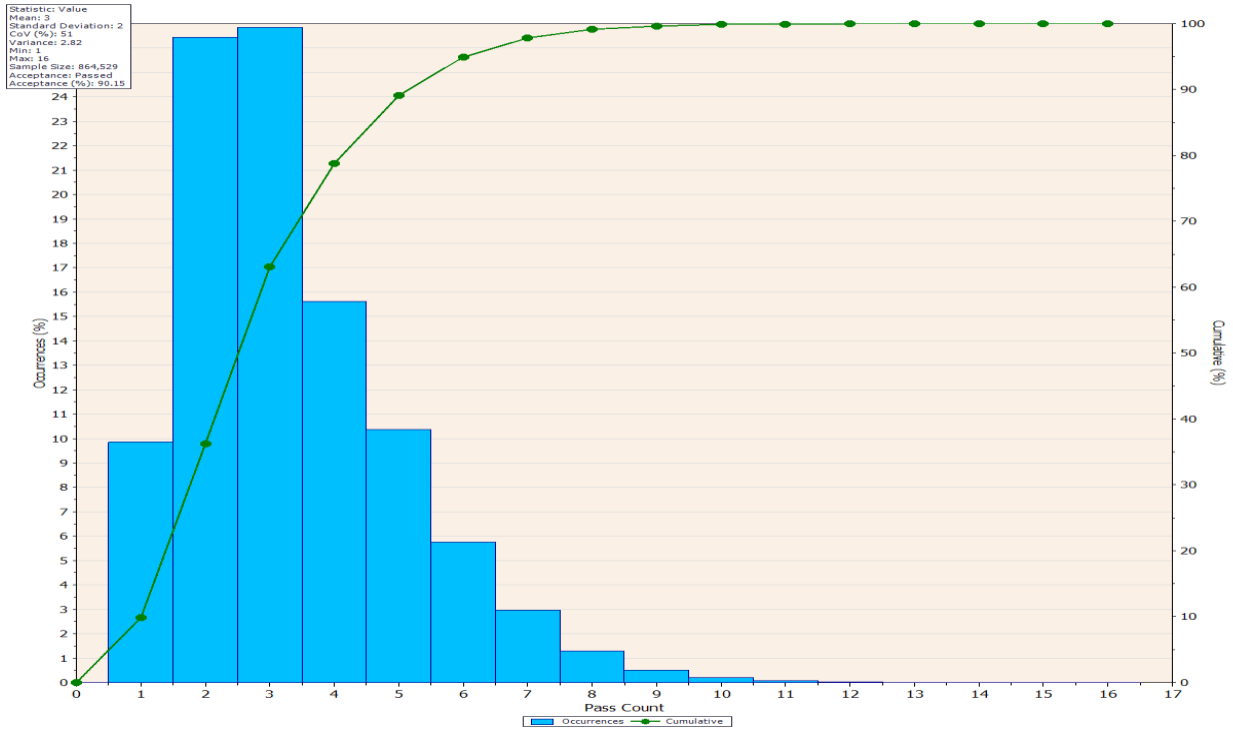
# Appendix A1 Clark Co CID 161060 - Coverage
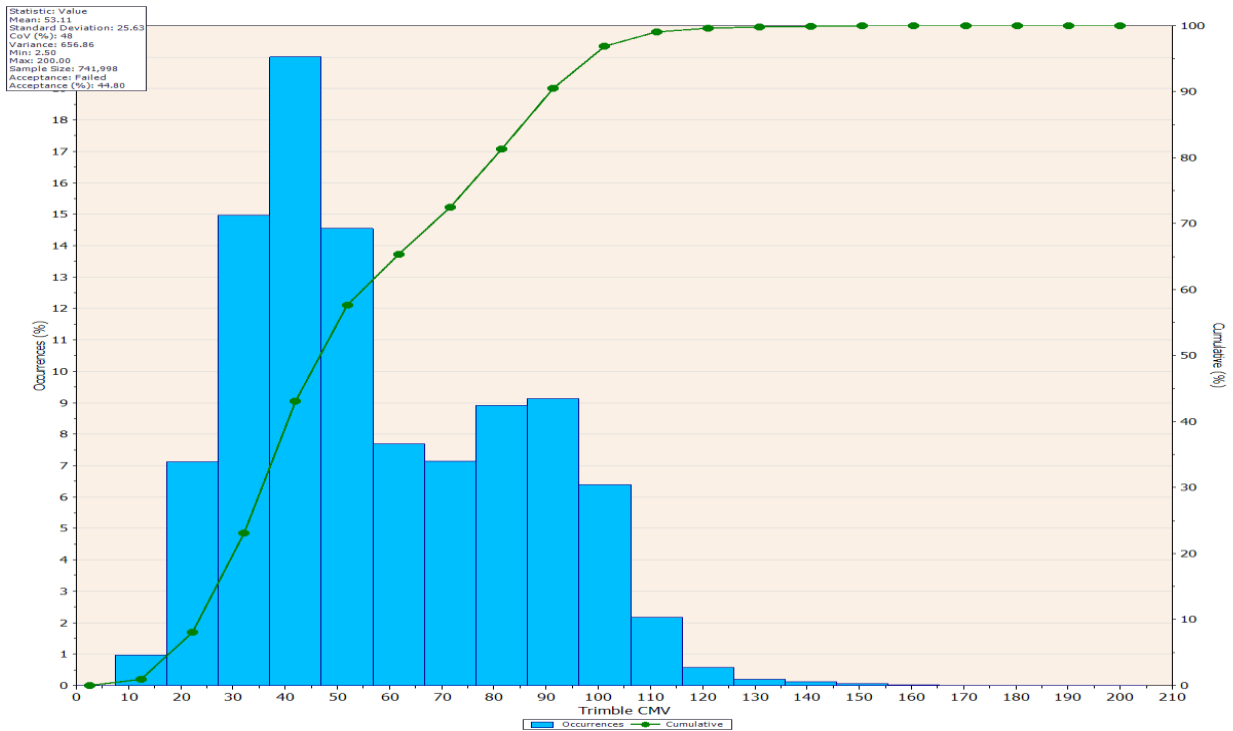


**Figure 1** Final Coverage — Pass Counts



**Figure 2** Final Coverage — ICMV

## Appendix A2 Clark Co CID 161060 - Correlation

y = -1.83x + 219.33; R² = 0.03; n = 25
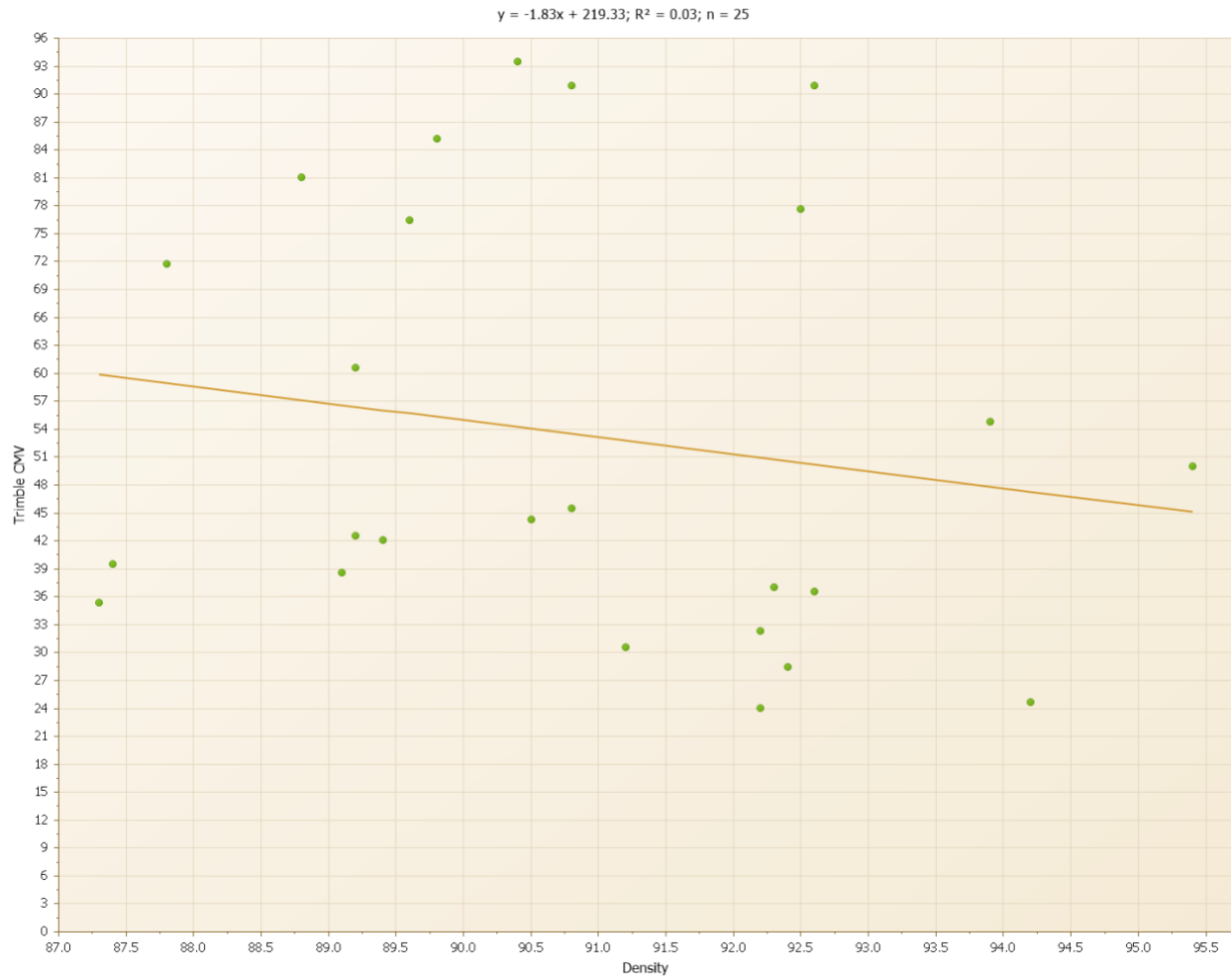


**Figure 3** Linear Regression

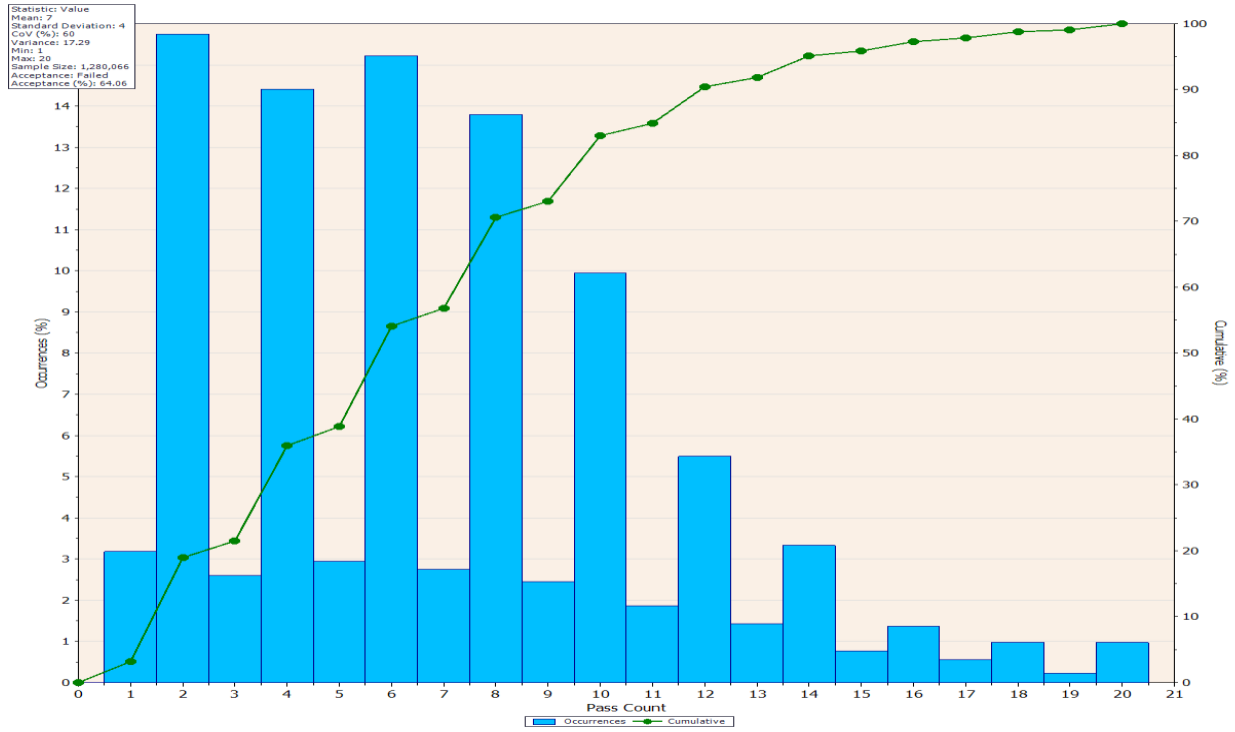## Appendix B1 Pike Co CID 161046 – Coverage (F&R Combined)



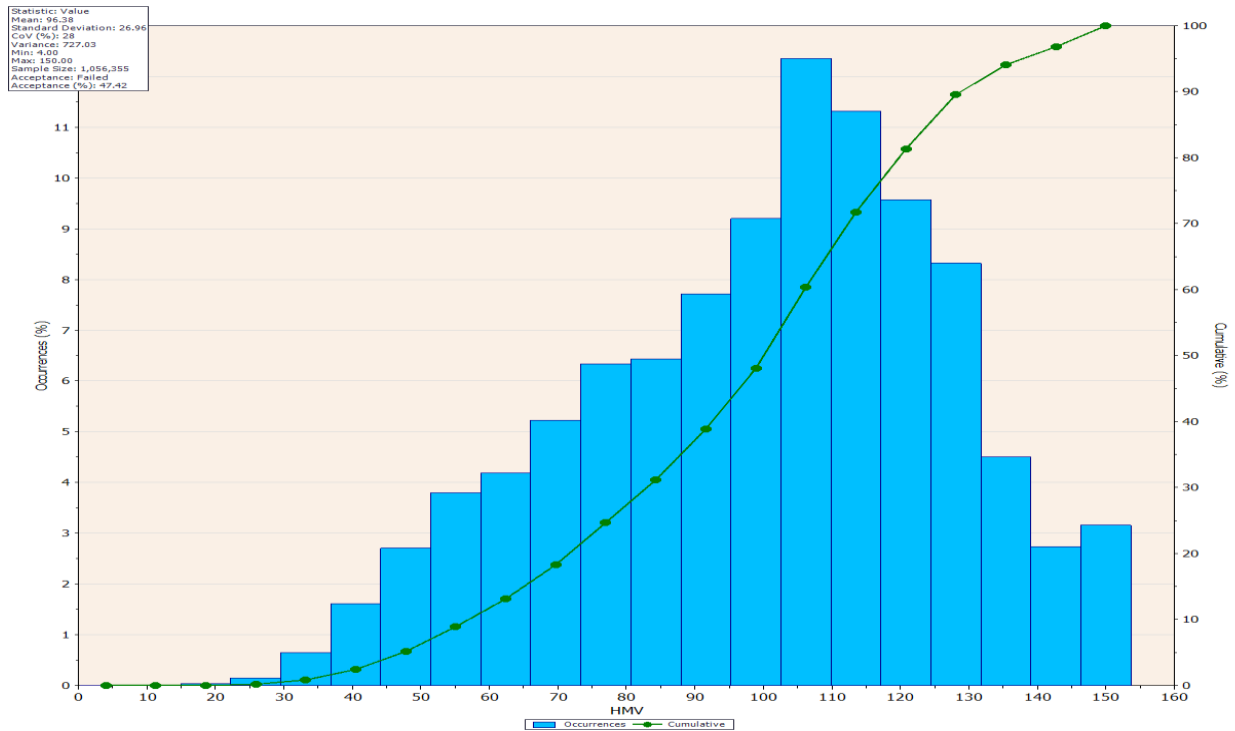**Figure 4** Final Coverage — Pass Counts



**Figure 5** Final Coverage — ICMV

# Appendix C1 Rockcastle Co CID 161270 – Coverage Base Lift 1
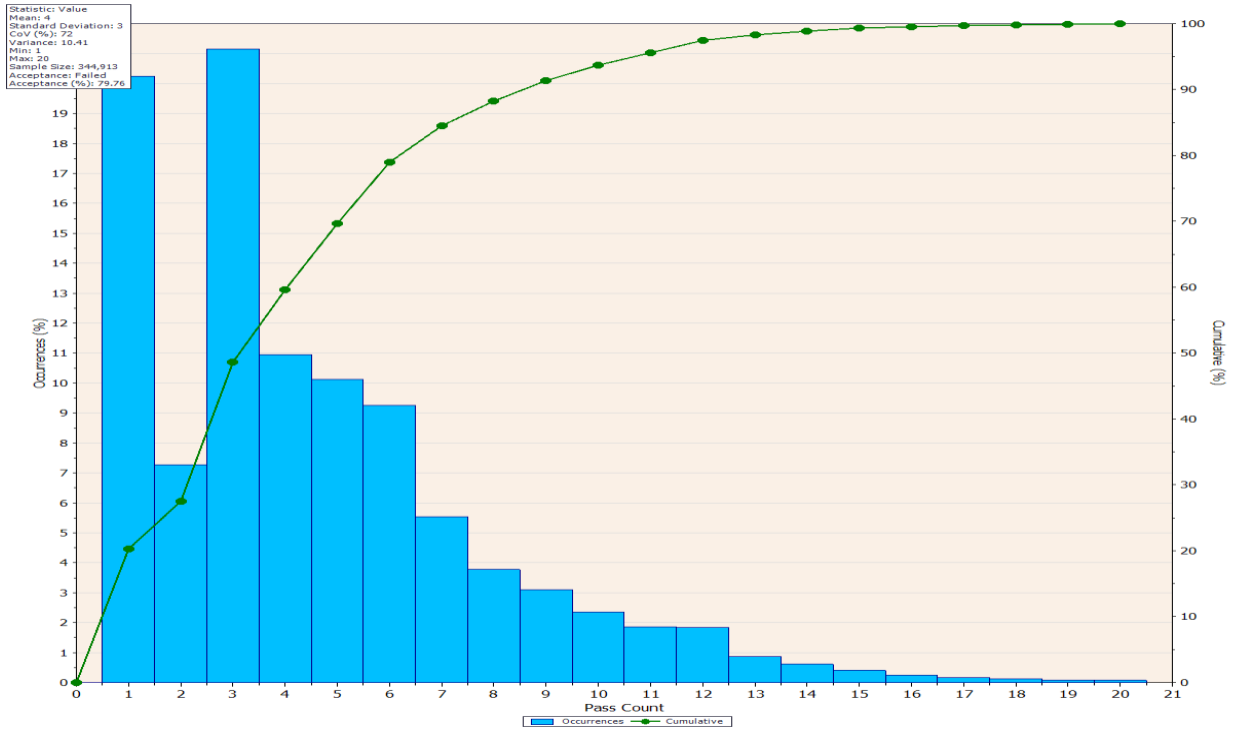


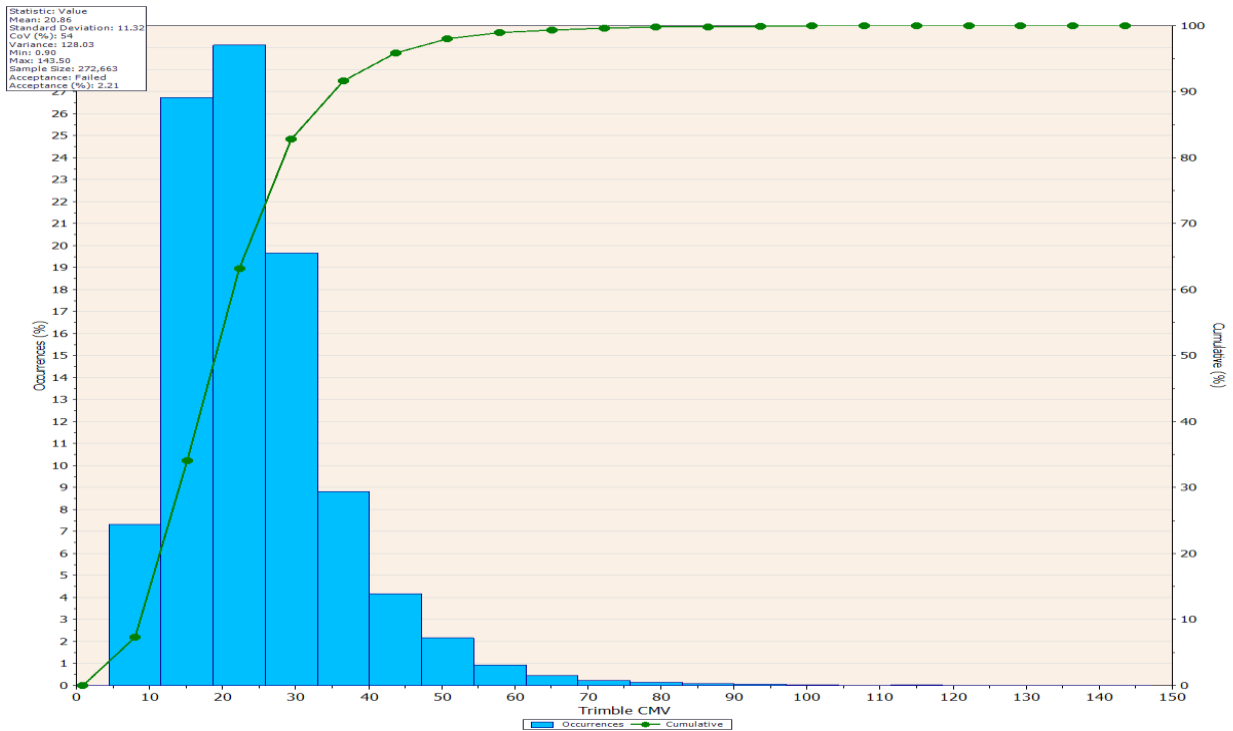**Figure 6** Final Coverage — Pass Counts



**Figure 7** Final Coverage — ICMV

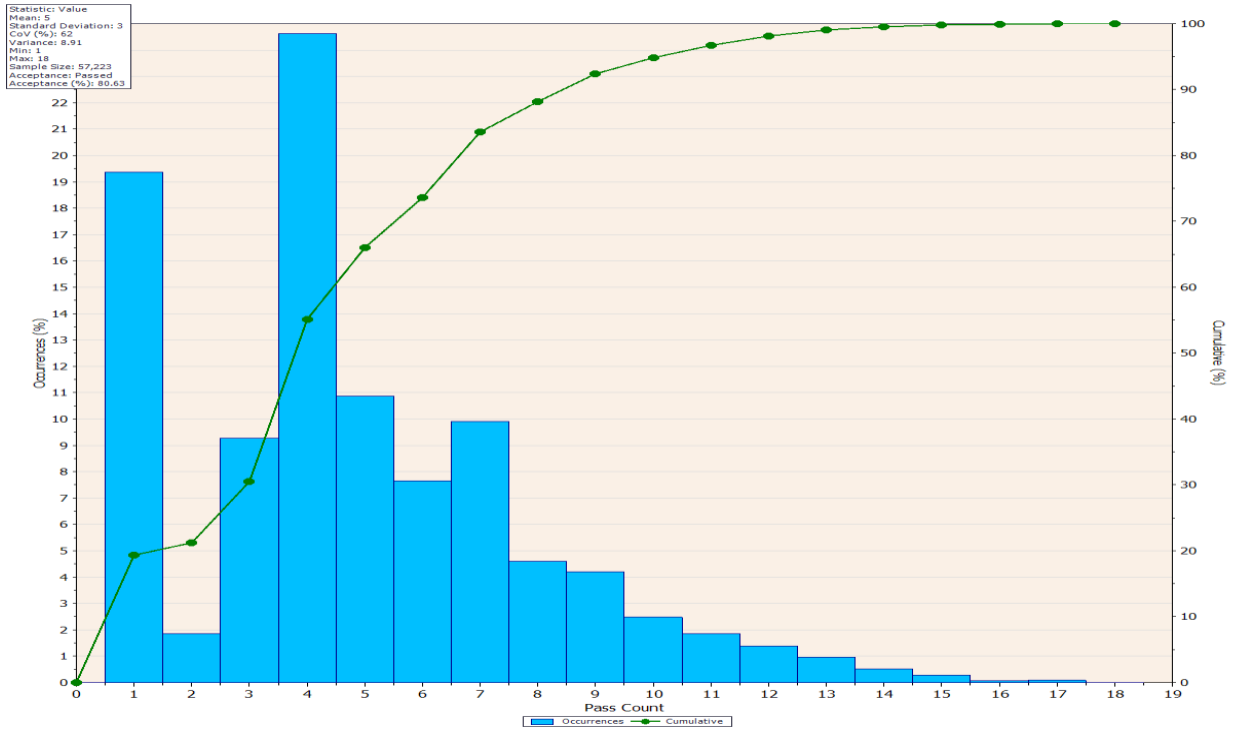# Appendix C2 Rockcastle Co CID 161270- Coverage Base Lift 2



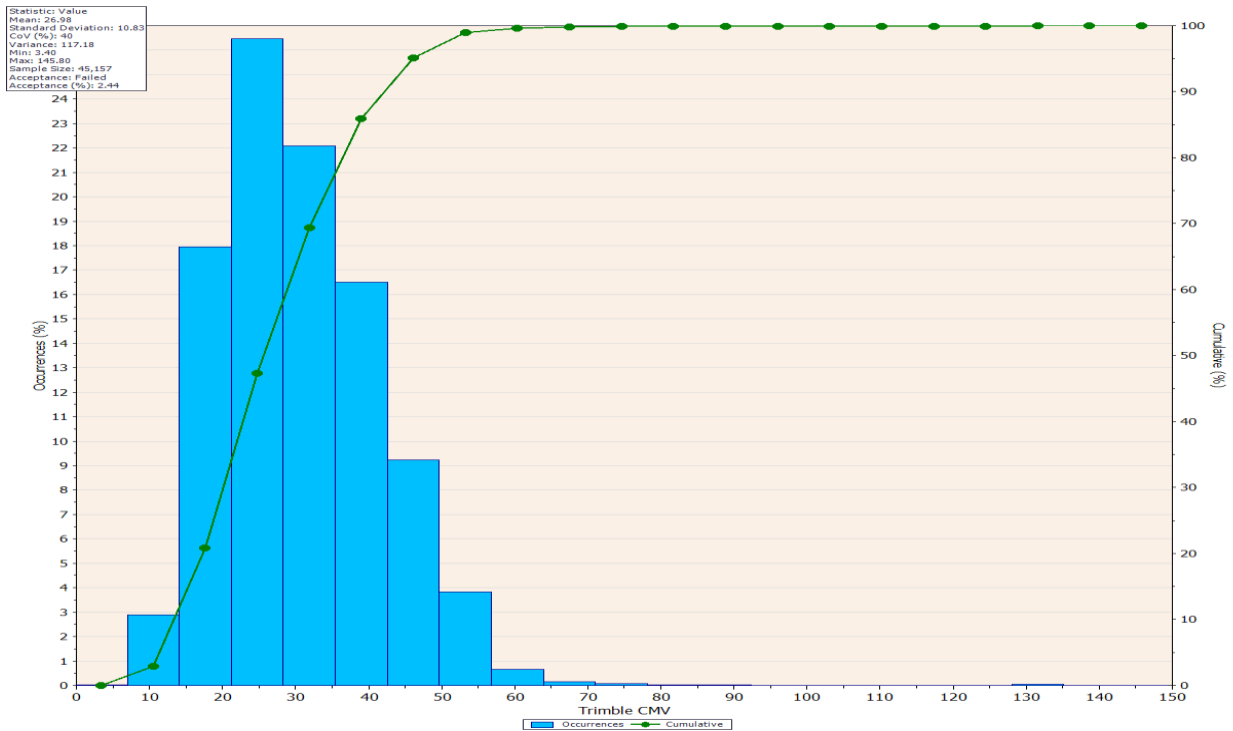**Figure 8** Final Coverage — Pass Counts



**Figure 9** Final Coverage — ICMV

# Appendix C3 Rockcastle Co CID 161270 Base Lift 1 and Base Lift 2
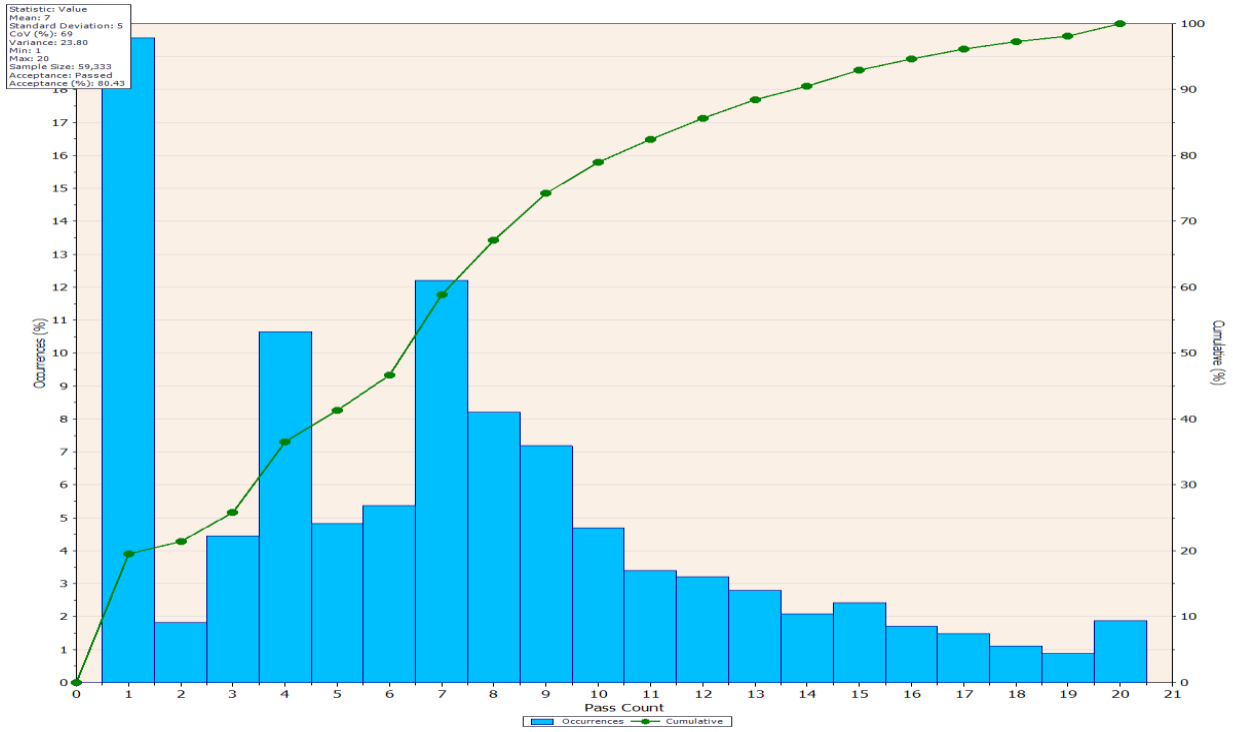


**Figure 10** Final Coverage — Pass Counts
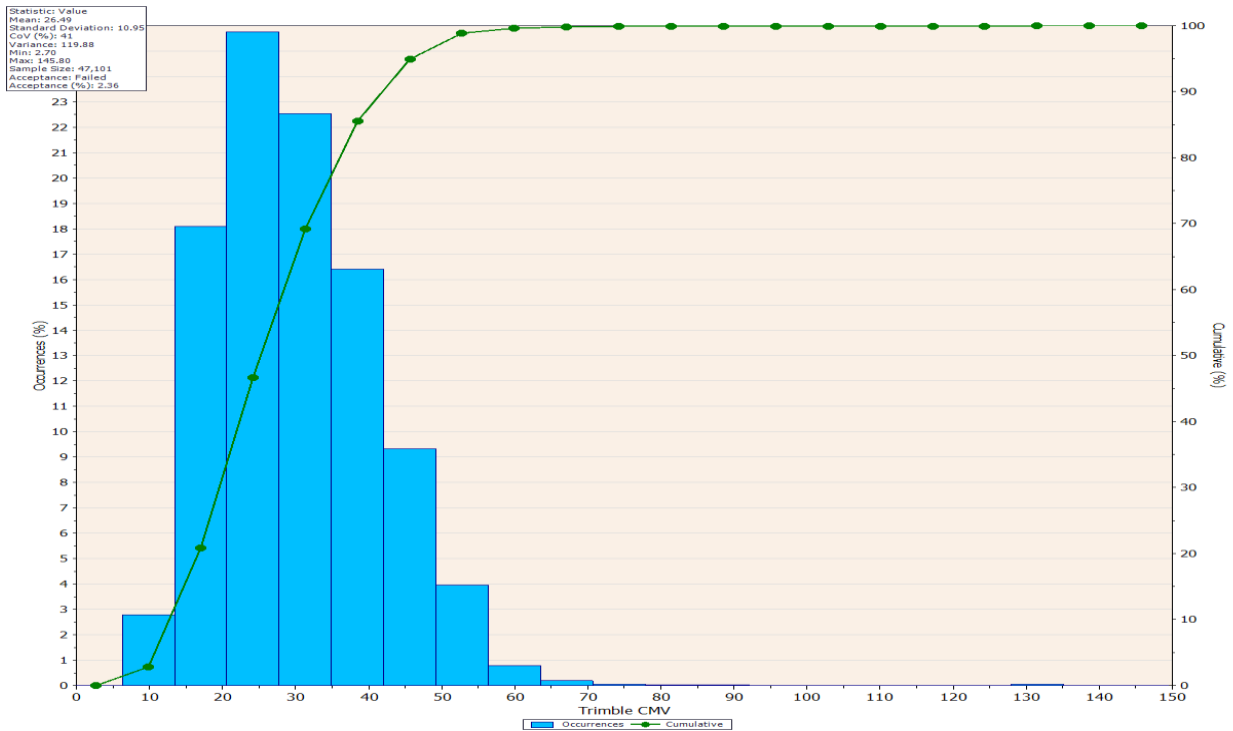


**Figure 11** Final Coverage — ICMV

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**Appendix D1 Adair Co CID 161261 Roller CB54XW**



Statistic: Value
Mean: 3
Standard Deviation: 1
CoV (%): 49
Variance: 1.78
Min: 1
Max: 20
Sample Size: 692,705
Acceptance: Failed
Acceptance (%): 9.46
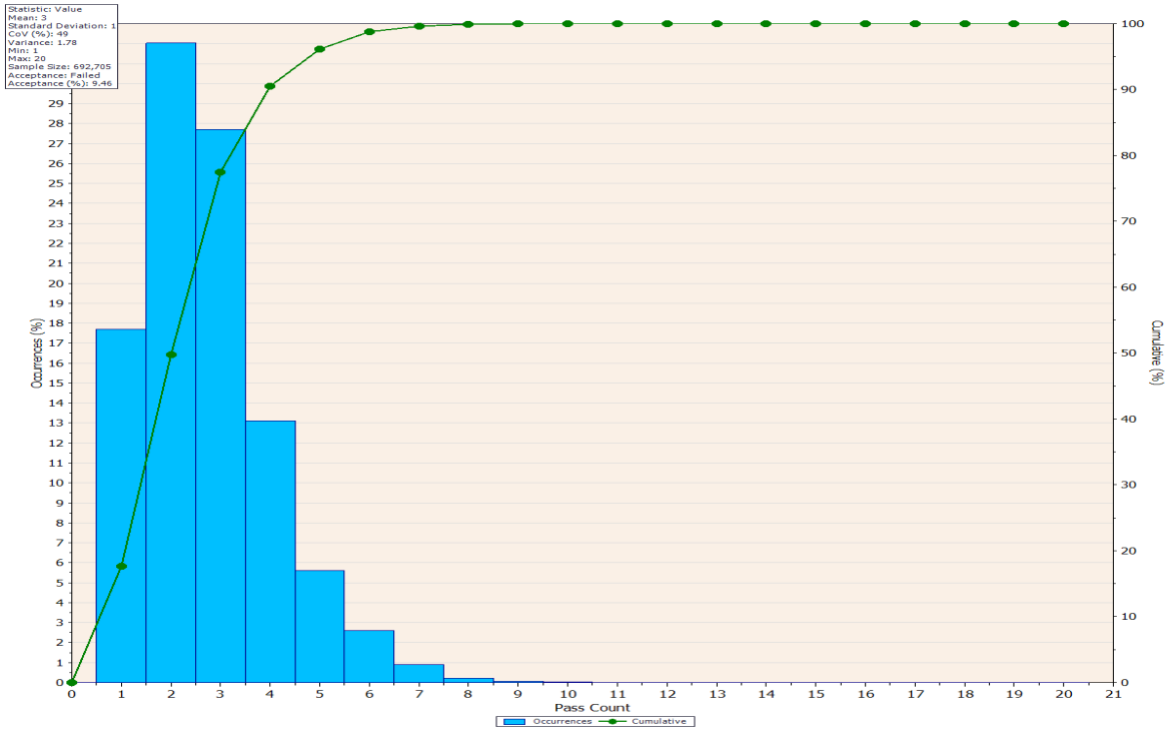
**Figure 12** Final Coverage — Pass Counts



Statistic: Value
Mean: 98.93
Standard Deviation: 21.92
CoV (%): 22
Variance: 480.36
Min: 3.90
Max: 191.60
Sample Size: 663,833
Acceptance: Passed
Acceptance (%): 98.67
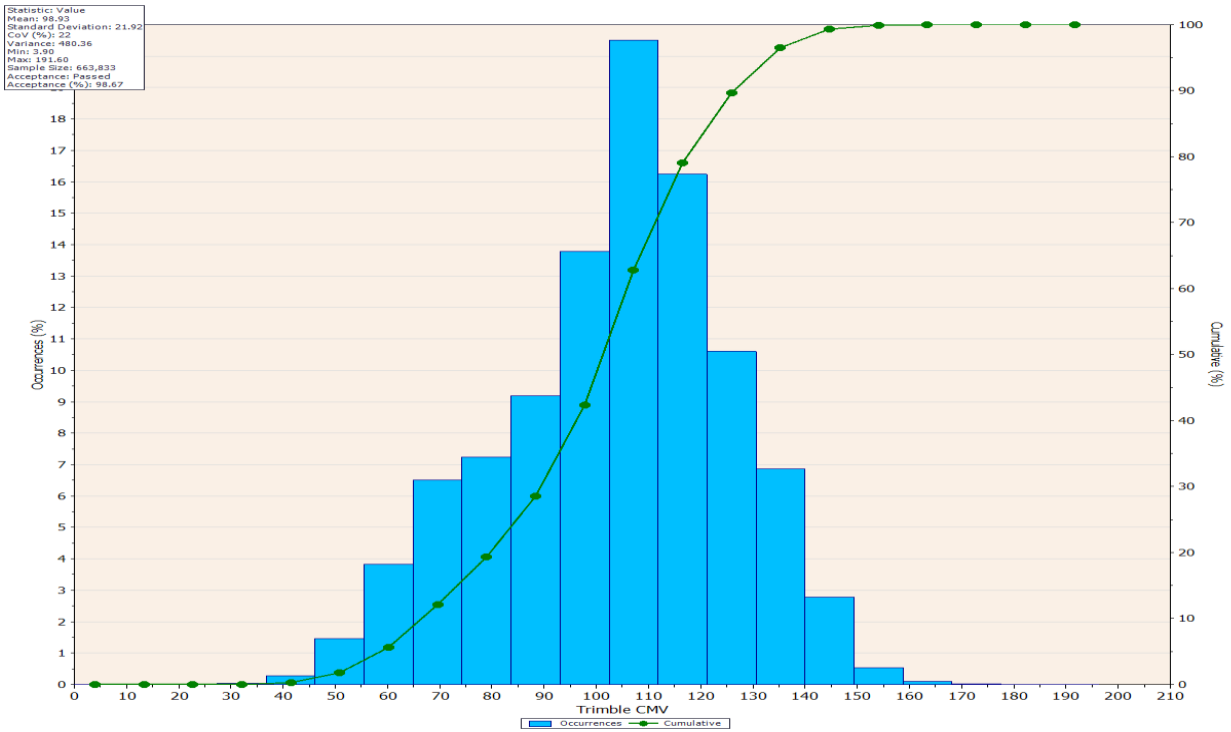
**Figure 13** Final Coverage — ICMV

# Appendix D2 Adair Co CID 161261 Roller CB54JLM



Statistic: Value
Mean: 3
Standard Deviation: 2
CoV (%): 51
Variance: 2.50
Min: 1
Max: 17
Sample Size: 693,710
Acceptance: Failed
Acceptance (%): 30.55
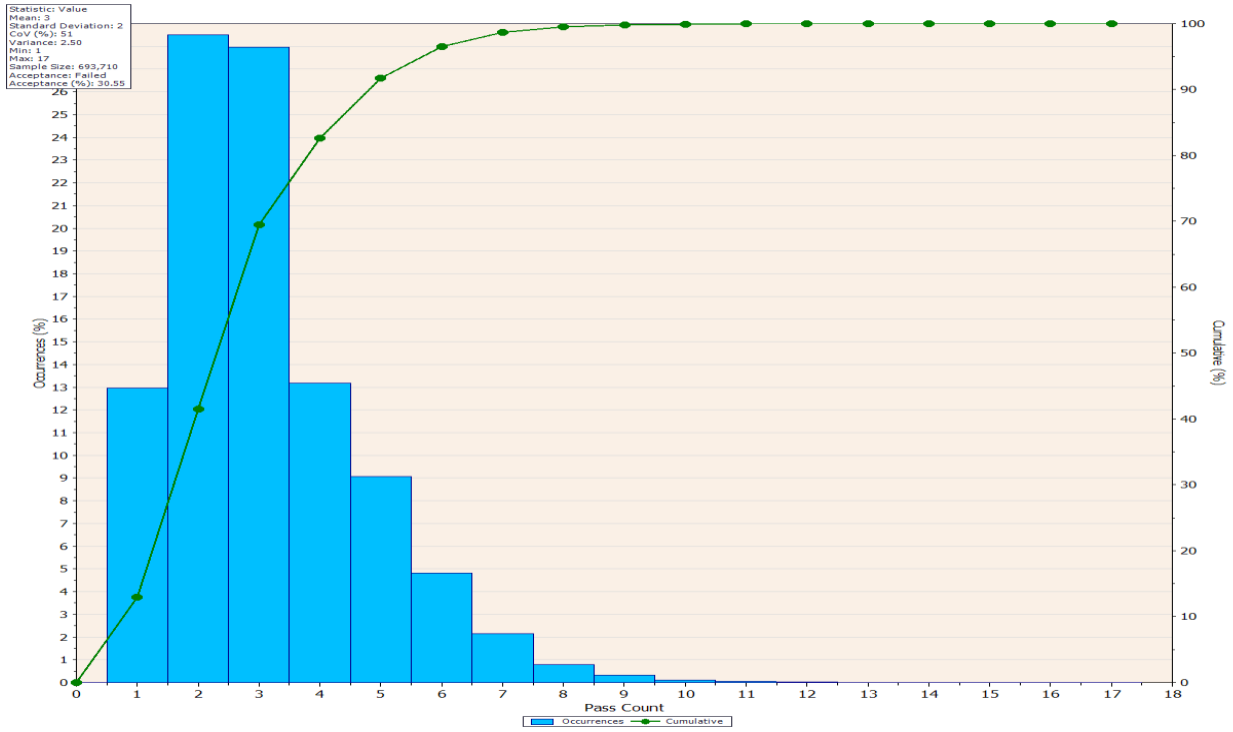
**Figure 14** Final Coverage — Pass Counts



Statistic: Value
Mean: 89.12
Standard Deviation: 21.44
CoV (%): 24
Variance: 459.62
Min: 3.10
Max: 196.50
Sample Size: 642,270
Acceptance: Passed
Acceptance (%): 96.96
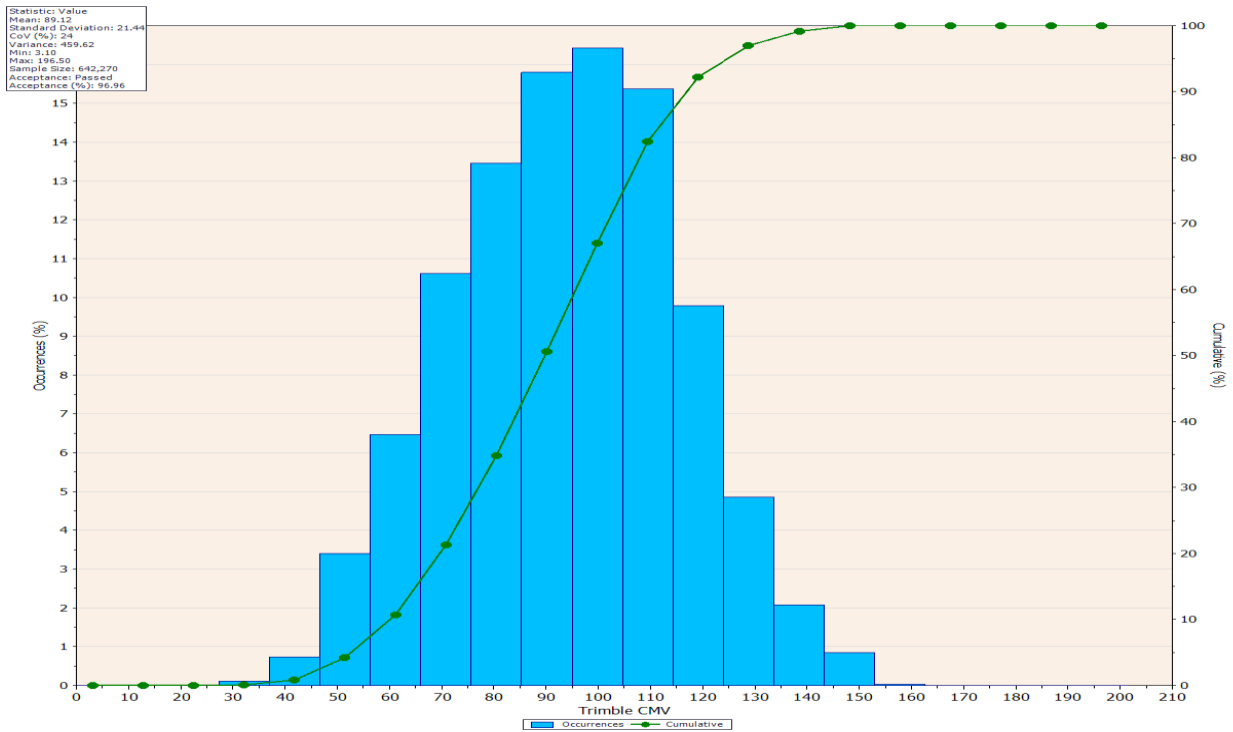
**Figure 15** Final Coverage — ICMV

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# Appendix E1 Warren Co CID 161052 ICMV39

Statistic: Value
Mean: 6
Standard Deviation: 3
CoV (%): 53
Variance: 10.19
Min: 1
Max: 20
Sample Size: 1,601,200
Acceptance: Failed
Acceptance (%): 78.59
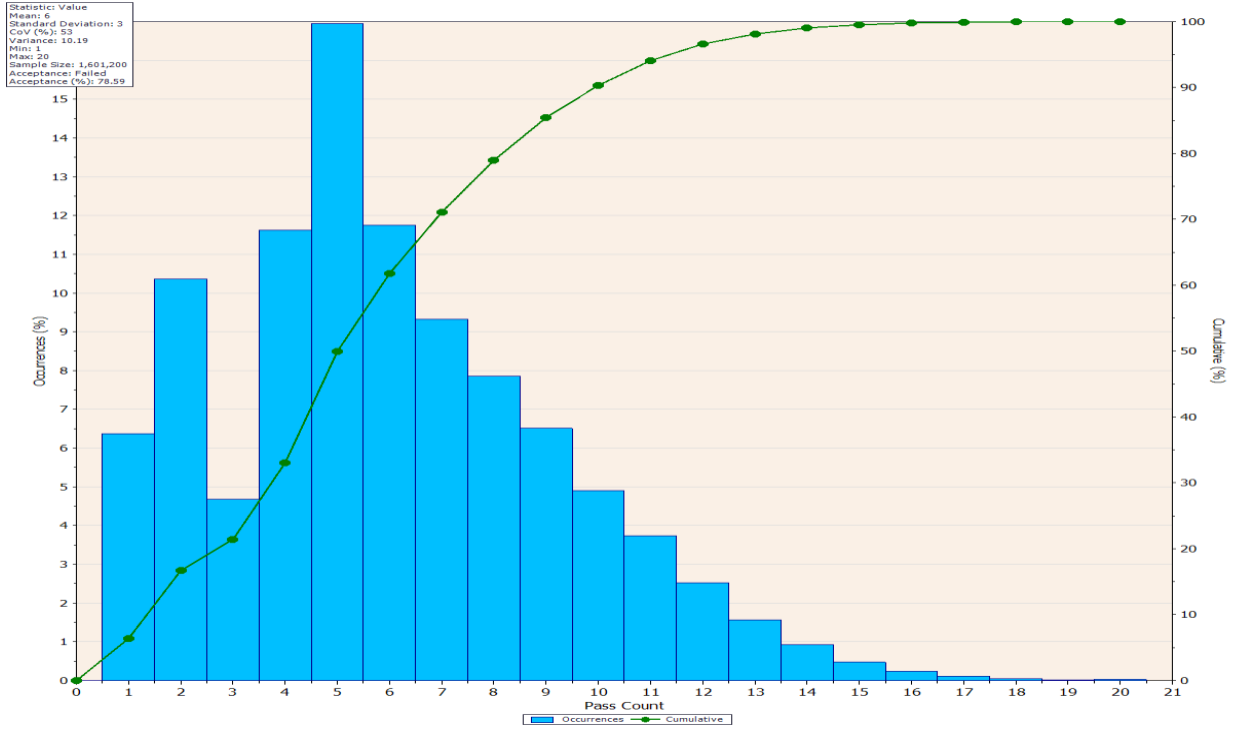
**Figure 16** Final Coverage — Pass Counts

Statistic: Value
Mean: 48.75
Standard Deviation: 17.95
CoV (%): 37
Variance: 322.37
Min: 0.10
Max: 146.80
Sample Size: 1,418,973
Acceptance: Failed
Acceptance (%): 72.97
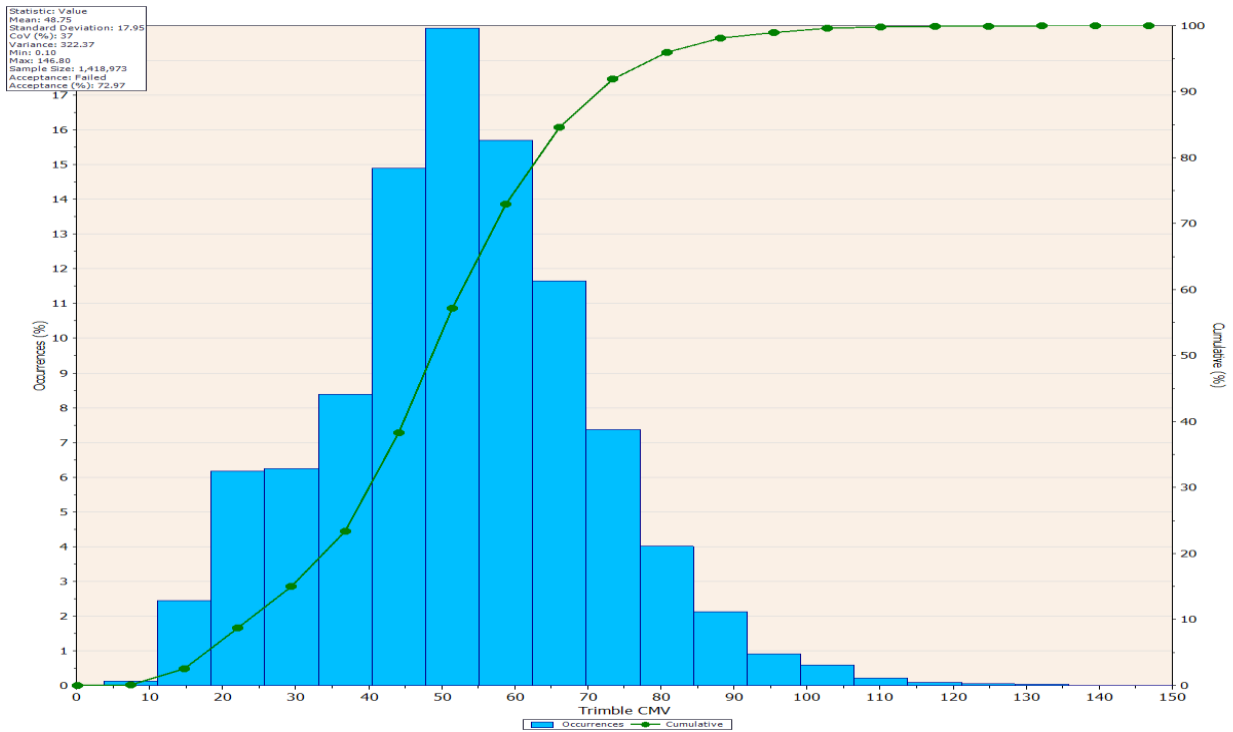
**Figure 17** Final Coverage — ICMV

**Appendix E1 Warren Co CID 161052 ICMV39**

y = 0.49x + -6.50; R² = 0.00; n = 78
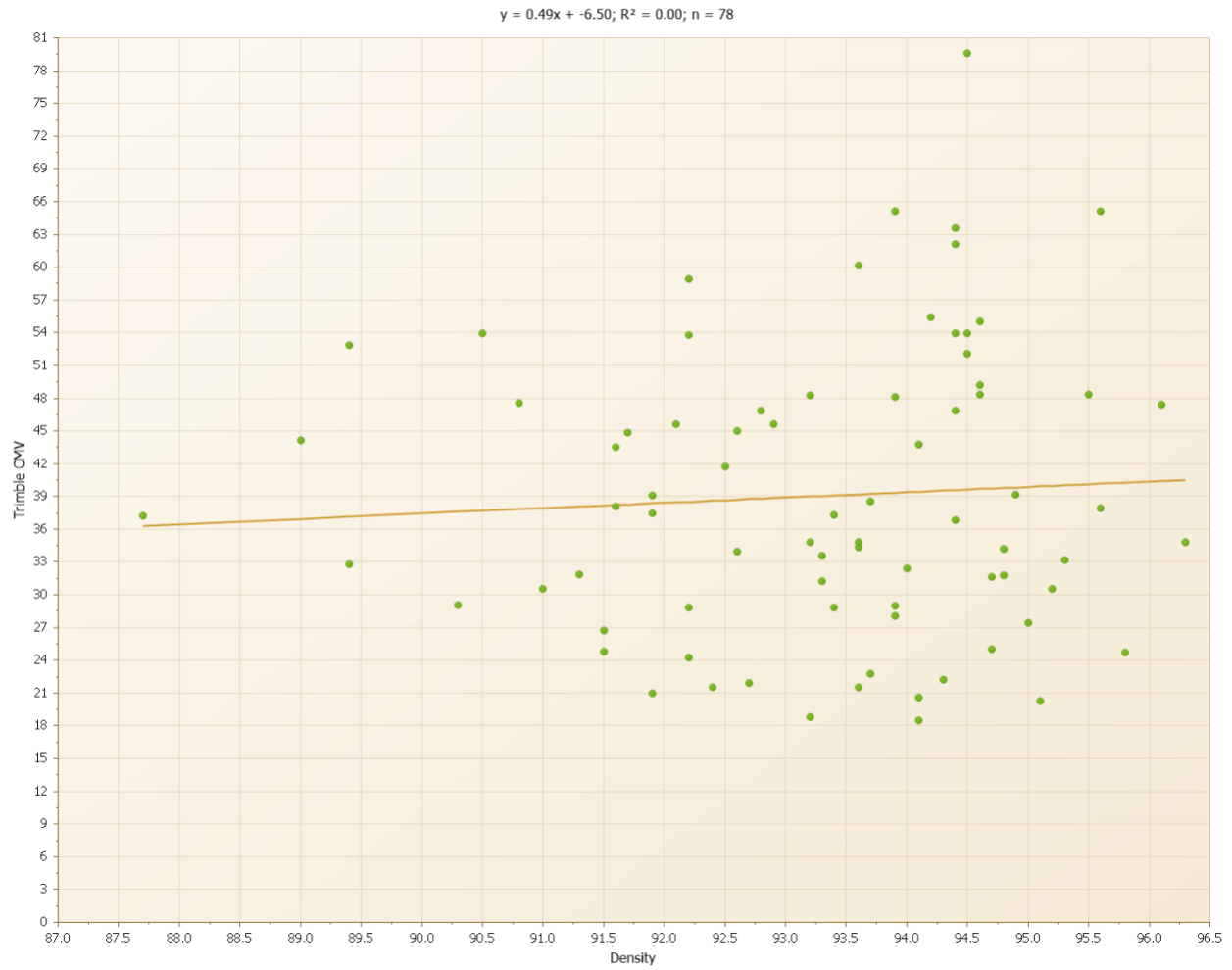


**Figure 18** Linear Regression

# Appendix E2 Warren Co CID 161052 ICMV25

Statistic: Value
Mean: 5
Standard Deviation: 3
CoV (%): 67
Variance: 10.72
Min: 1
Max: 20
Sample Size: 213,361
Acceptance: Failed
Acceptance (%): 63.11
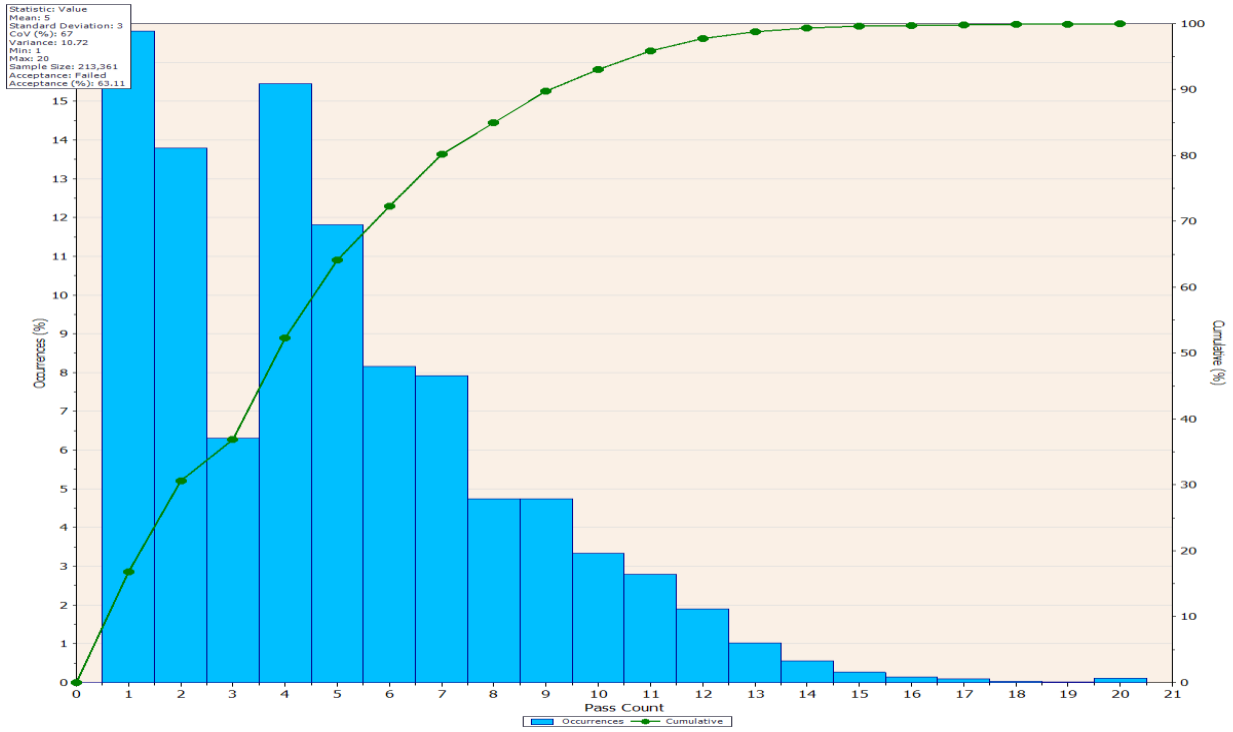
**Figure 19** Final Coverage — Pass Counts

Statistic: Value
Mean: 40.18
Standard Deviation: 16.00
CoV (%): 40
Variance: 256.02
Min: 1.30
Max: 116.50
Sample Size: 166,719
Acceptance: Passed
Acceptance (%): 80.32
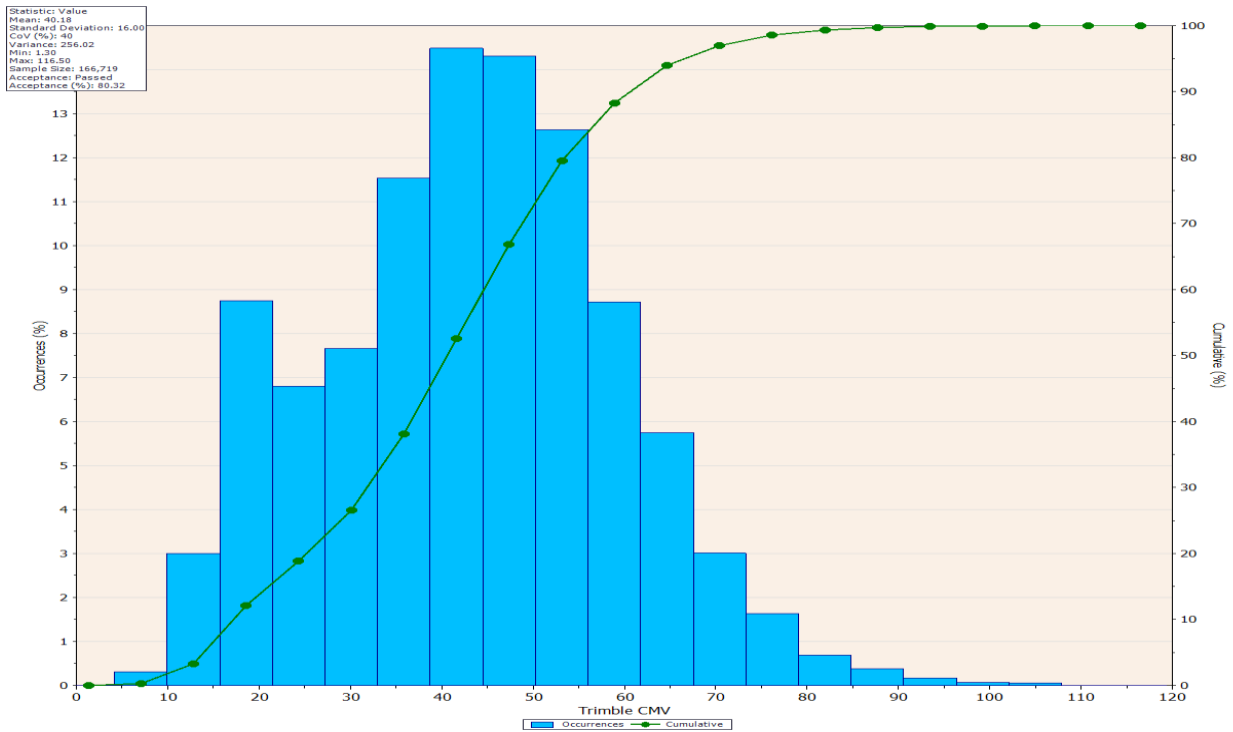
**Figure 20** Final Coverage — ICMV

**Appendix E2 Warren Co CID 161052 ICMV25**



$y = 5.82x + -515.16; R^2 = 0.19; n = 7$

**Figure 21** Linear Regression

**Appendix F IC Special Construction Note**

## SPECIAL NOTE FOR INTELLIGENT COMPACTION OF ASPHALT MIXTURES

This Special Note will apply when indicated on the plans or in the proposal. Section references herein are to the Department's Standard Specifications for Road and Bridge Construction current edition.

**1.0     DESCRIPTION.** Provide and use Intelligent Compaction (IC) Rollers for compaction of all asphalt mixtures.

**2.0     MATERIALS AND EQUIPMENT.** In addition to the equipment specified in Subsection 403.02, a minimum of one (1) IC roller is to be used on the project at all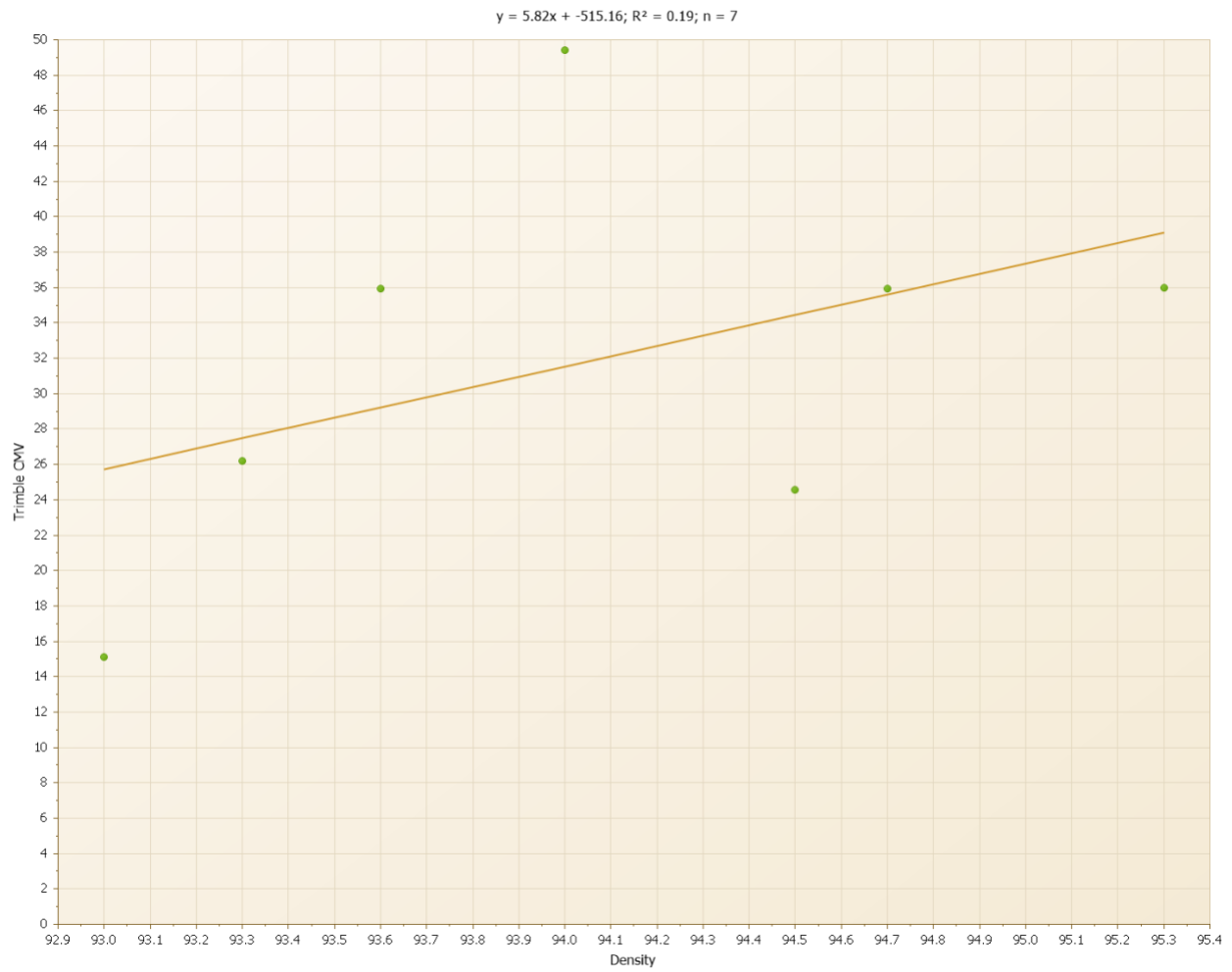 times. The Contractor may elect to only use one (1) IC roller for compaction as the breakdown or intermediate roller. All IC rollers will meet the following minimum characteristics:

1) Are self propelled double-drum vibratory rollers equipped with accelerometers mounted in or about the drum to measure the interactions between the rollers and compacted materials in order to evaluate the applied compactive effort. The IC rollers must have the approval of the Engineer prior to use. Examples of rollers equipped with IC technology can be found at www.IntelligentCompaction.com.

2) Are equipped with non-contact temperature sensors for measuring pavement surface temperatures.

3) The output from the roller is designated as the IC-MV which represents the stiffness of the materials based on the vibration of the roller drums and the resulting response from the underlying materials.

4) Are equipped with integrated on-board documentation systems that are capable of displaying real-time color-coded maps of IC measurement values including the stiffness response values, location of the roller, number of roller passes, machine settings, together with the material temperature, speed and the frequency and amplitude of roller drums. Ensure the display unit is capable of transferring the data by means of a USB port.

5) Are equipped with a mounted Global Positioning System GPS radio and receiver either a Real Time Kinematic (RTK-GPS) or Global Navigational Satellite System (GNSS) units that monitor the location and track the number of passes of the rollers. Accuracy of the positioning system is to be a minimum of 12 inches.

**3.0  WORK PLAN.** Submit to the Engineer an IC Work Plan at the Preconstruction Conference and at least 2 weeks prior to the beginning construction. Describe in the work plan the following:

1. Compaction equipment to be used including:
   - Vendor(s)
   - Roller model(s),
   - Roller dimensions and weights,
   - Description of IC measurement system,
   - GPS capabilities,
   - Documentation system,
   - Temperature measurement system, and
   - Software.

2. Roller data collection methods including sampling rates and intervals and data file types.

3. Transfer of data to the Engineer including method, timing, and personnel responsible. Data transfer shall occur at minimum twice per day or as directed by the Engineer, and is to be either electronic or digital. If the contractor elects to use a proprietary real time cloud data collecting and distribution system (ex. Visionlink) the Cabinet requests an the ability to access the data through this service.

4. Provide the Engineer with a new laptop computer with the following minimum requirements: Windows 7 Pro 64bit, 2.0GHz processor, 32GB RAM, 500GB hard drive, DVD drive (reads and writes DVD/CD), and 14 inch display. **The Cabinet retains possession of the equipment upon completion of the project.**

5. Provide the Section Engineer the following new GPS survey equipment; this is a sole source item to ensure compatibility with the Cabinet's existing equipment, **The Cabinet retains possession of the equipment upon completion of the project:**

| Item | Part No. | Description | Quantity |
|------|----------|-------------|----------|
| 1 | R10-001-60 | Trimble R10, internal 410-470 MHz radio | 2 |
| 2 | TSC3-01-1120 | Trimble TSC3, w/Trimble Access, with internal radio QWERTY Keypad | 1 |
| 3 | SA-ROADS-P | Trimble Access – Roads Perpetual License | 1 |
| 4 | 43169-00 | Rod - 2.0m Carbon Fiber Range Pole with Bipod | 1 |
| 5 | 82758-00 | Trimble TSC3 Accessory - Range Pole Bracket | 1 |
| 6 | 74450-14 | TDL 450H Field Battery Charger Kit | 1 |
| 7 | 74450-96 | TDL 450H – 35W Radio System Kit; 450-470 MHz | 1 |
| 8 | 12178 | Tripod - Wooden Medium Duty | 1 |
| 9 | 74450-50-70 | Antenna kit with 1.8m mast | 1 |
| 10 | 28959-00 | Tripod-Adjustable height 2M for GPS base | 1 |

6. Training plan and schedule for roller operators, project foreman, project surveyors, and Cabinet personnel; including both classroom and field training. Training should be conducted at least 1 week before beginning IC construction. The training is to be performed by a qualified representative(s) from the IC Roller manufacture(s) to be used on the project.

**4.0 CONSTRUCTION.** Do not begin work until the Engineer has approved the IC submittals and the IC equipment.

Follow requirements established in Section 400 for production and placement, materials, equipment, acceptance plans and adjustments except as noted or modified in this Specification. Provide the Engineer at least one day's notice prior to beginning construction or prior to resuming production if operations have been temporarily suspended. Ensure paving equipment complies with all requirements specified in Section 400. The IC roller temperatures will be evaluated by the Department with the data from a Paver Mounted Infrared Temperature Gauge.

A. Pre-Construction Test Section(s) Requirements

1. Prior to the start of production, ensure the proper setup of the GPS, IC roller(s) and the rover(s) by conducting joint GPS correlation and verification testing between the Contractor, GPS representative and IC roller manufacturer using the same datum.

   1. Ensure GPS correlation and verification testing includes the following minimum processes:

      a. Establish the GPS system to be used either one with a base station or one with mobile receivers only. Ensure all components in the system are set to the correct coordinate system; then,

      b. Verify that the roller and rover are working properly and that there is a connection with the base station; then,

      c. Record the coordinates of the two edges where the front drum of the roller is in contact with the ground from the on-board, color-coded display; then,

      d. Mark the locations of the roller drum edges and move the roller, and place the mobile receiver at each mark and record the readings; then,

2. Compare coordinates between the roller and rover receivers. If the coordinates are within 12.0 in. of each other, the comparison is acceptable. If the coordinates are not within 12.0 in., diagnose and perform necessary corrections and repeat the above steps until verification is acceptable.

3. Do not begin work until acceptable GPS correlation and verification has been obtained.

4. The Contractor and the Department should conduct random GPS verification testing during production to ensure data locations are accurate. The recommended rate is once per day with a requirement of at least once per week.

5. All acceptance testing shall be as outlined in Standard Specifications section 400.

B. Construction Test Section(s) Requirements

Construct test section(s) at location(s) agreed on by the Contractor and the Engineer within the project limits. The test section is required to determine a compaction curve of the asphalt mixtures in relationship to number of roller passes and to the stiffness of mixture while meeting the Department in-place compaction requirements. All rollers and the respective number of passes for each is to be determined via control strip each time a material change, equipment change or when the Engineer deems necessary.

Conduct test section(s) on every lift and every asphalt mixture. Ensure test section quantities of 500 to 1,000 tons of mainline mixtures. Operate IC rollers in the low to medium amplitude range and at the same settings (speed, frequency) throughout the section while minimizing overlapping of the roller, **the settings are to be used throughout the project with no changes.** After each roller pass, the qualified technician from the contractor observed by the Department will use a nondestructive nuclear gauge that has been calibrated to the mixture to estimate the density of the asphalt at 10 locations uniformly spaced throughout the test section within the width of a single roller pass. The density readings and the number of roller passes needed to achieve the specified compaction will be recorded. The estimated target density will be the peak of the average of the nondestructive readings within the desired compaction temperature range for the mixture. The IC roller data in conjunction with the Veda software will create an IC compaction curve for the mixture. The target IC-MV is the point when the increase in the IC-MV of the material between passes is less than 5 percent on the compaction curve. The IC compaction curve is defined as the relationship between the IC-MV and the roller passes. A compaction curve example is as follows:
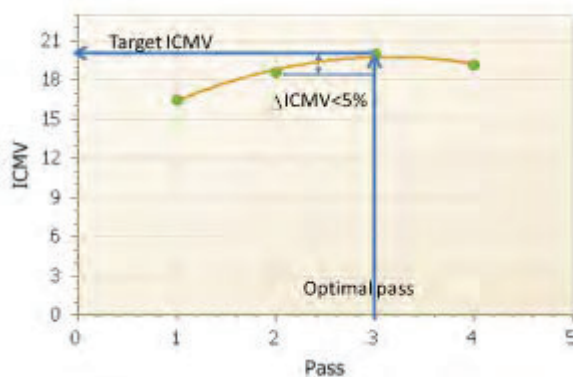


Subsequent to the determination of the target IC-MV, compact an adjoining $> 250 < 500$ tons section using same roller settings and the number of estimated roller passes and allow the Department to verify the compaction with the same calibrated nondestructive nuclear gauge following the final roller pass. **The Department will obtain cores at 10 locations (No cores for calibration are to be taken in the surface layer, use non-destructive density results only!!)** uniformly spaced throughout the test section within the width of the single roller. Obtain GPS measurement of the core locations with a GPS rover. Use the Veda software to perform least square linear regression between the core data and IC-MV in order to correlate the production IC-MV values to the Department specified in-place air voids. A sample linear regression curve example is as follows.
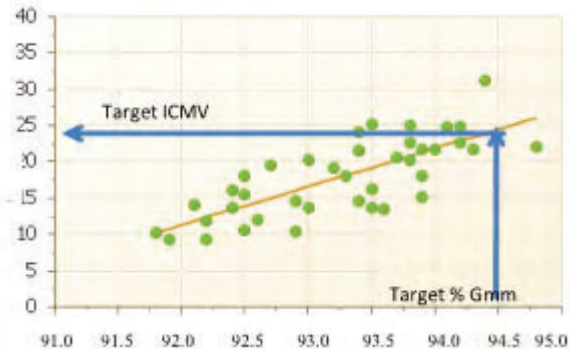
C. Construction Requirements
Use the IC roller on all lifts and types of asphalt within the limits of the project.

Ensure the optimal number of roller passes determined from the test sections has been applied to a minimum coverage of 80% of the individual IC Construction area. Ensure a minimum of 75% of the individual IC Construction area meets the target IC-MV values determined from the test sections.

Do not continue paving operations if IC Construction areas not meeting the IC criteria are produced until they have been investigated by the Department. Obtain the Engineer's approval to resume paving operations. Non-IC rollers are allowed to be used as the third roller on the project; one of the breakdown or the finish rollers is to be equipped with IC technology.

IC Construction areas are defined as subsections of the project being worked continuously by the Contractor. The magnitude of the IC Construction areas may vary with production but must be at least 750 tons per mixture for evaluation. Partial IC Construction areas of < 750 tons will be included in the previous area evaluation. IC Construction areas may extend over multiple days depending on the operations.

The IC Construction Operations Criteria does not affect the Department's acceptance processes for the materials or construction operations

**5.0    MEASUREMENT.** The Department will measure the total tons of asphalt mixtures compacted using the IC roller(s). Compaction is to be performed by a minimum of one IC roller, material compacted by rollers not equipped with properly functioning IC equipment will not be accepted for payment of the bid item asphalt mixtures IC rolled. Use of non-IC rollers can be accepted on small areas due to equipment malfunctions at the written approval of the Engineer. Paving operations should be suspended for equipment malfunctions that will extend over three days of operation.

**6.0 PAYMENT.** The Department will make payment for the completed and accepted quantities under the following:

1.  Payment is full compensation for all work associated with providing IC equipped rollers, all required survey equipment and computer, transmission of electronic data files, two copies of IC roller manufacturer software, and training.

2.  Delays due to GPS satellite reception of signals to operate the IC equipment or IC roller breakdowns will not be considered justification for contract modifications or contract extensions.

| Code | Pay Item | | Pay Unit |
|------|----------|--|----------|
| 24781EC | Intelligent Compaction for Asphalt | TON | |