Barcode Quality Step By Step

Connecting the Dots from the Verification Report to Solving Your Barcode Problems

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Introduction

This document discusses the print quality of linear barcodes, based on ANSI/ISO specification 15416 and its predecessor known as Traditional Verification.

Traditional Verification was never a standard or a specification because traditional test methodology was never developed, as will be discussed later.

Traditional Verification is based mostly on element (bar and space) width measurement and comparison to nominal or idea widths. ANSI/ISO specification is built almost entirely on the reflective attributes of the symbol. This is a more reliable predictor of barcode performance “in the field” because barcode scanners function based on reflectance, not bar or space widths. But Traditional Verification addresses some essential barcode attributes and most verifiers will test attributes from both methods.

The basic building block for ANSI/ISO verification is the Scan Reflectance Profile (SRP) which is not an attribute of the grading system. The SRP is a graphical map of the reflectance properties of the barcode symbol from which almost all of the attributes of the symbol are measured and graded. Think of the SRP as the “eyeballs” that allow you to look at the barcode in terms of its reliability and likelihood of success as a data storage tool.

Unlike other barcode quality manuals, this one will not only introduce you to the 2 Traditional Verification parameters and the 9 ANSI/ISO parameters for barcode quality, it will also attempt to “connect the dots” and relate these parameters to the common print methods. If you are a flexo or a litho printer, for example, this guide will help you understand what each parameter means in terms of your process, and what to do if, for example, the barcodes you are printing are downgraded due to a problem with Decodability or Modulation.

Why Traditional Verification parameters are so-called is self evident—this was the beginning of measuring barcode quality as a predictor of barcode performance.

Why is the ANSI/ISO specification referred to as if it were one technical document? Isn’t ANSI different than ISO and aren’t there two different specifications?

The ANSI and ISO specifications are substantially the same. The chief difference is the way grading is expressed. ANSI grading is in alphabetical letter form (A-F); ISO grading is numerical (1.0–4.0) with decimal fractions. This allows the ISO grading system to be more nuanced than the ANSI system. In the ANSI system, a C grade could be a low C, almost a D, or a high C, almost a B, and you wouldn’t know it.

It is important to note that there are actually two ANSI/ISO specifications relating to linear barcodes. ANSI/ISO 15416, the “methodology” specification, relates to what to grade, how to grade it and how to report it. Think of this as the “measuring stick.” ANSI/ISO 15426-1, the “conformance” specification,
relates to the performance of the test device (the verifier) itself, evaluating it against a known, traceable standard to ensure that it is testing and grading the printed symbol accurately. Think of this as making sure the “measuring stick” is trustworthy.

Finally, how important is any of this? There are skeptics who claim that ANSI/ISO compliance adds needless expense to an already-expensive technology, basically a “glorified scanner”. Why not use a non-glorified scanner at a fraction of the cost of a verifier?

A scanner cannot perform the duties of a verifier because a scanner is a go/no-go gauge. It either decodes the barcode or it doesn’t. It doesn’t tell you why or when the symbols in a print run are about to fail. Furthermore, scanners are not manufactured to a performance standard; different scanners perform differently. Some are more fault tolerant, others are more unforgiving. A verifier—even those from different manufacturers, is designed to test the barcode to a known standard. Theoretically all verifiers should grade a given barcode the same.

As the use of barcodes has expanded beyond the consumer commodity supply chain into more critical roles in food safety and pharmaceutical trace and track the importance of reliable, predictable barcode performance has increased drastically. The barcode is a vital link and failure to perform is more than an inconvenience. There is substantial potential risk and liability associated with poorly performing barcodes. Not using ANSI/ISO compliant testing tools makes no sense when there is so much riding on the quality of the barcode.

Traditional Verification is based on linear measurement of elements (bars and spaces) and comparison of those measurements with nominal or “perfect” specified values, plus a measurement of reflectivity in a formula called Print Contrast Signal or PCS.

PCS is based on the formula \((R_{\text{max}} - R_{\text{min}})/R_{\text{max}}\) where the result must be 75% or higher. PCS is no longer used, but it established the guideline that barcode symbols must have dark features (bars) in a light field (quiet zones and spaces). Reverse polarity barcodes do not function.

The flaw in the linear measurement of elements in the Traditional Verification methodology is that there was no methodology. Some practitioners performed measurements from leading edge to leading edge or consecutive bars, which negates the effects of press gain. Others measured a bar-space pair. Still others measured bars, then spaces, then bars. The lack of a standardized procedure made it impossible to compare results between practitioners. In fact Traditional Verification proved to be a poor predictor of end user scanning performance and led to the development and adoption of the ANSI/ISO verification methodology.

Why do many ANSI/ISO verifiers include Traditional Verification and why does it matter? Because scanning is an imprecise, unpredictable art. The more information you can gather about the condition of a barcode, the better.
Reflectance is defined as the variable amount of light at a given wavelength as it bounces off an object at a predictable angle. In this case, the variable amount of light is due to the reflective properties of a barcode comprised of bars and spaces of various widths; the wavelength of light is 660nm.

The Scan Reflectance Profile or SRP is the basic foundation of ANSI/ISO verification for linear barcodes. It is a graphical representation of the light and dark reflectance values of the entire symbol, left-to-right, from quiet zone to quiet zone.

While the SRP itself is not an ANSI/ISO parameter for barcode quality, it provides the information for six of the 9 parameters for barcode quality, having to do with the reflective attributes of the barcode.

Because it is based on reflectivity, the ANSI/ISO method of verification is more similar to how scanners work than Traditional verification which is based on physical measurement of bar/space widths. This makes SRP-based verification more reliable as a predictor of barcode behavior at the point-of-use.

However, the SRP is not very helpful in diagnosing barcode problems and figuring out how to adjust a printing method to improve results. In other words, if the verification report indicates a problem with Modulation or Decodability for example, looking at the Scan Reflectance Profile doesn’t help to understand what is causing the problem.

Traditional verification methods are much better at this, so most ANSI/ISO compliant verifiers include some Traditional verification grading for this reason.
Edge Determination is accomplished by counting the bar-and-space transitions at the Global Threshold. The count is how a scanner determines if the symbol is a known type; a non-matching count will cause this parameter to fail.

Edge Determination is a measure of whether the number of bars and spaces matches a known, valid type of barcode symbol. It is \textit{not} a measure of how well the bars and spaces can be detected. The count is either valid or not and therefore this is a pass/fail parameter.

This is an example of the importance of the SRP. In order to count bars and spaces, the first step is to locate the Global Threshold or GT on the Scan Reflectance Profile. The Global Threshold is positioned exactly half way between the highest reflectance and lowest reflectance values on the Scan Reflectance Profile.

The formula for locating the Global Threshold is:

\[
GT = R_{\text{min}} + \frac{SC}{2}
\]

The Scan Reflectance Profile provides everything needed in this formula.

\(R_{\text{min}}\) is the lowest or minimum reflectance value found in the barcode. The \(R_{\text{min}}\) is found in the bars or the barcode, which must have the lowest reflectivity.

\(R_{\text{max}}\) is the highest or maximum reflectance value found in the barcode. \(R_{\text{max}}\) is found in the spaces and the quiet zones which must have the highest reflectivity.

\(SC\) or Symbol Contrast is a simple subtraction of the \(R_{\text{min}}\) from \(R_{\text{max}}\).

\[GT = \text{Global Threshold} \]

\[\text{Minimum Reflectance}\]
The bars in the barcode must be the Rmin value and the background which comprises the spaces and quiet zones must be the Rmax value. Although a reversed image could theoretically produce an acceptable Minimum Reflectance, it would violate the Print Contrast Signal system for barcodes, which dictates that bars must be Rmin; quiet zones and background (spaces) must be Rmax.

The reflectance value for the lowest reflecting bar must be less than or equal to one half the highest reflecting space (or quiet zone) in the barcode. Thus, if the highest reflectance space or quiet zone is 75%, the Rmin of at least one space must be no more than 37.5%.

Since Rmin either is or isn’t equal to or less than 50% of Rmax, this is a pass-fail parameter.

Obviously, if Minimum Reflectance is marginal or failing, improving it can only be accomplished by increasing the Rmax or decreasing the Rmin.

Think of this parameter as a benchmark. The lowest reflecting bar and the highest reflecting space (or quiet zone) establishes a sort of benchmark for the symbol. All other Rmin and Rmax values are compared to this—none will be better and some will be worse. Because of this, it is important that the Rmin and Rmax values be as uniform as possible across the barcode.

Symbol Contrast
This one is easy—Symbol Contrast or SC is a straight subtraction of Rmin from Rmax; the higher the contrast, the better the grade. Here’s how grading works:

\[
\begin{align*}
SC &= \geq 70\% = A \\
SC &= \geq 55\% = B \\
SC &= \geq 40\% = C \\
SC &= \geq 20\% = D \\
SC &= < 20\% = F
\end{align*}
\]

Obviously low Symbol Contrast grades can be improved either by increasing Rmax, decreasing Rmin, or both.

Not so obvious is the way certain substrates (Rmax) and certain inks (Rmin) behave. Bare plastic containers such as shampoo bottles may not be as reflective as one might assume; this is also true of bare aluminum cans. These materials, while appearing to be highly reflective, can actually be highly refractive, scattering reflected light rather than sending it back toward the light source and into a receptor (see Fig 1).

It is for this reason that you will see some soft drink cans where the barcode is reverse printed—the spaces (Rmax) are printed and the bars (Rmin) remain, represented by the bare aluminum surface.
Symbol Contrast problems are common in printing barcodes on corrugated because the Rmax of the bare kraft substrate is usually so low, the Rmin cannot be low enough to create enough difference to achieve a grade higher than a D. The solution would be to print a white patch or knock-out over the bare kraft and print a black barcode in a second pass, but customers are often unwilling to pay the additional cost.

Symbol Contrast is not an unknown problem in other printing methods, but those situations would be caused by ill-advised Rmin and Rmax color combinations or highly reflective Rmin colors on highly reflective Rmax substrates common in flexo printing.

Modulation
Scanners decode barcodes based on the reflective differences of dark and light elements (bars and spaces). Scanners do not measure wide bars or spaces and detect linear differences between them as compared to narrow bars or spaces. It’s all done based on reflective differences. This is how a scanner “sees” and decodes.

In an ideal world, the low reflectivity of a narrow bar and a wide bar would be about the same, and the high reflectivity of a narrow space and a wide space would likewise be about the same. But even when the barcode is perfectly printed, there will be slight differences in the reflectivity of narrow and wide elements. The measurement and grading of this difference is Modulation.

Here’s the formula: \[ \text{Modulation} = \frac{\text{ECmin}}{\text{SC}} \]

ECmin is Edge Contrast Minimum  
SC is Symbol Contrast  
Here’s how the grading works:

- \( \text{Modulation} \geq 70\% = A \)  
- \( \text{Modulation} \geq 60\% = B \)  
- \( \text{Modulation} \geq 50\% = C \)  
- \( \text{Modulation} \geq 40\% = D \)  
- \( \text{Modulation} < 40\% = F \)

Modulation grades how much reflective difference there is between narrow bars and wide bars, and narrow spaces and wide spaces. In an ideal world, narrow and wide bars would be equally low reflectance, and narrow and wide spaces would be equally high reflectance—but in the real world they are not.

Modulation worsens when the reflectance differences between narrow and wide elements, whether they are bars or spaces, increases. So, for example, when the bars experience press gain, narrow spaces will lose reflectivity more than wide spaces. The reflective difference between narrow and wide spaces will increase, and Modulation will be downgraded.

If the reflectivity of the narrow spaces is degraded to the point where they begin to fail to penetrate the Global Threshold on the Scan Reflectance Profile, Edge Determination will be incorrect, and the scanner will begin to fail to decode the symbol.
The verification report below pertains to the poorly printed symbol above.

Ideally these two values would be the same—but they are obviously not the same. The difference between these two points is Modulation.

Here the C grade for Modulation grade isn’t that bad. But the SRP shows very clearly the differences in the reflectance values of wide spaces in comparison to narrow spaces. The reason is excessive ink spread—notice the Average Bar Gain of 43% in the Summary window (upper left).
Modulation problems are not uncommon to all printing methods. This example is from a thermally printed label but modulation problems are seen in flexo printing and litho printing too.

Defects

As the name implies, Defects are artifacts in the spaces or gap or exclusion in the bars. The technical term for such an undesired feature is a Element Reflectance Non-uniformity or ERN. Remember, ANSI/ISO verification is all based on reflectance, so a defect is something that causes a non-uniformity in the expected reflectance value of a bar or space (element).

The smaller the amount of non-uniformity, the higher the grade for the Defects parameter.

The Defects parameter is comparable to Modulation, except the Defects grading pertains to each singular element (bar or space), whereas Modulation pertains to reflective differences between alike elements (narrow and wide bars or narrow and wide spaces); Defects problems will also appear on the Scan Reflectance Profile in a comparable fashion to Modulation problems.
Defects is graded as follows:

- Defects $= \leq 15\% = A$
- Defects $= \leq 20\% = B$
- Defects $= \leq 25\% = C$
- Defects $= \leq 30\% = D$
- Defects $= > 30\% = F$
Decodability

Decodability is not an easy parameter to understand.

It is briefly defined as the amount of tolerance remaining for the scanner, after the imaging process.

The challenge in understanding decodability is in relating it a visual inspection of the barcode, and how to adjust the printing process to improve a low decodability grade.

Decodability is a graded parameter, but we cannot provide a breakdown of the grading hierarchy because decodability is calculated differently for different symbologies.

Decodability describes the accuracy of the printed barcode image as it relates to the specification or ideal rendering of the symbol—and this varies depending on the symbol type.

For example, some symbologies have only two element widths, others have many. The encoded characters in some symbologies are self-contained and separated from each other by a standard gap or space, others are separated by a variable gap or space which is part of the encodation scheme. Different symbol types have different start/stop patterns.

The decoding formula can be written to accommodate various amounts of inaccuracy in the printed image—and this is why decodability varies between various symbol types.

A low decodability grade is often—but not always—accompanied by a low grade on other parameters including Modulation. Excessively spread bars are a common cause of a low decodability grade.

A much more subtle and difficult to detect problem which results in a low decodability grade is mismatched digital resolution—which is also difficult to describe. Users have the opportunity to define the resolution of the barcode in the barcode design software. Usually this is done in DPI (dots per inch) but sometimes it is described in different units of measure. The printing device will also have its own resolution, and sometimes in a different unit of measure. The potential problem is when the resolution of the design file and the resolution of the printing device mismatch.

Imagine that the digital design information that is being sent to the printer is asking for 400 DPI but the printer can only resolve 203 DPI (believe it or not, this is a common resolution for most thermal and thermal transfer printers).

The printer attempts to do what the digital information is demanding by “pixel rounding”, slightly modifying the widths of bars or spaces, or relocating them to slightly different positions in relationship to each other. The printer does this because it can only resolve the digital information to its native DPI and not to some fraction of a pixel since there is no such thing as a portion of a pixel.
The havoc this wreaks to the integrity of the barcode image is what triggers the parameter Decodability. The barcode looks fine, and the bars may not exhibit any excessive bar width gain and no other parameters may be signaling problems.

About the only way to conclusively identify the source of the problem is to insist on accurate information about how the barcode was designed, or to physically measure the barcode with a microscope.
Decode

When the scanner detects a correct pattern of bars and spaces, known to represent a set or series of characters that are consistent with the specifications for a valid symbology, the parameter Decode can be said to pass. Obviously this either happens or doesn’t; Decode is a pass or fail parameter.

Decode is accomplished (or not) by virtue of a count of transitions of various widths from light to dark reflectance values across the symbol.

This occurs at the Global Threshold line on the Scan Reflectance Profile, but because the barcode cannot be decoded, no graphic representation of the barcode is shown.

The decode error is usually indicated as an error message in the verification report.
Close examination of this barcode reveals the problem.

The symbol does not have the correct number of bars and spaces on the right half of the barcode, hence it will not have the correct number of transitions through the Global Threshold to make it a valid UPC symbol.

Here is a verification report showing a Decode failure on a different symbol. Notice the transition failures at the Global Threshold.
Quiet Zones

Quiet Zones are the blank areas at the beginning and at the end of the barcode. All linear barcodes require quiet zones, and the minimum width is specific to the symbology type.

Because scanners decode the symbol by detecting reflectance differences across the barcode, it is important to position the barcode within a defined area, devoid of extraneous reflective differences such as screening, graphics, text, package corners, shrink wrap seams or folds, or anything else that the scanner might detect and add to the element count on the Scan Reflectance Profile. Decoding occurs perpendicular to bar height, so quiet zones are only necessary to the left and right of the barcode—not top and bottom.

Note how the SRP graphically charts the violation of the right Quiet Zone.
It is also important that the quiet zones as well as the entire background behind the barcode be a uniform Rmax value. Quiet zones or symbol background of varying Rmax values will cause the Global Threshold line to shift between the varying Rmax and lowest Rmin values across the symbol. This can lead to problems with Modulation, Decodability and Decode.

Quiet Zone Failure

Quiet Zone Failure
Quiet Zone Failure

Marginal QZ
Marginal QZ—will fail when barcode is spread or pressure distorts bearer bar
Scan Grade and Symbol Grade

Scan Grade is the grade for each individual scan across a symbol. It is not unusual for there to be slight variation in scan grades as the verifier is moved up and down the barcode.

In the ANSI/ISO grading system the scan grade is the lowest grade for any parameter. In other words, the scan grade is not averaged between the parameters or otherwise calculated in any way: the lowest parameter grade is the scan grade. This is because a failure in any one parameter can cause the decoding of the barcode to fail.

Symbol Grade is the average of multiple scan grades. The ANSI/ISO grading system recommends that the Symbol Grade be the average of ten scan grades, but fewer than ten scan grades can be averaged if the barcode does not have sufficient height for the operator to easily take ten scan grades in discreet locations.

[Image of a barcode scanner output with labels indicating Symbol Average Grade and Last Scan Grade.

Structure and Margin fields indicate variations in individual reports in the ten-scan sequence.]
Interpreting Scannability from Symbol Grade

An ANSI “A” or ISO 4.0 Symbol Grade does not “guarantee” that a barcode will successfully scan everywhere. Nor does an ANSI “F” or ISO 1.0 Symbol Grade “guarantee” that a barcode will fail everywhere.

Symbol Grade is a guideline, a predictor but not a certification of scanning success. This is because scanning technology is an ever-changing, ever-broadening sea of varying optics, varying electronics and varying firmware, all of them aging and operated with varying degrees of rough handling, all in different and varying environments.

The unit of measure for the verifier grade protocol is one scan. This is also known as “first read rate”. A barcode with Symbol Grade A will generally scan successfully on the first try.

Symbols achieving a Symbol Grade B will not be as high quality as Symbol Grade A barcodes; one or more of the ANI/ISO parameters is downgraded to a B; the unit of measure or first read rate will be lower. These symbols will likely require rescanning to be decoded successfully.

Symbol Grade C barcodes will need to be rescanned even more than Symbol Grade B barcodes. Rescanning means redundant scanning of the same symbol, and more frequent rescanning of different examples of the same symbol. It is important to understand that the performance of a single barcode does not necessarily predict the quality of an entire print run.

A symbol with a Symbol Grade D will require multiple scans in different parts of the barcode to decode successfully. When Symbol Grade D results can be anticipated, such as barcodes printed on corrugated, users should specify scanners that perform best in that application.

F grade symbols are unlikely to scan successful in most scanning environments. Users sometimes believe that F grade symbols are actually acceptable because the verifier was able to decode them. The significant thing is the Symbol Grade, not the successful decode. Verifiers and scanners differ in this regard.

How the Symbol Grade is obtained is an important consideration. The verification process should never be “optimized”. The test samples should be representative of the entire print run, usually drawn from the beginning and the end of the run, with in-process samples pulled periodically during the run.

The tested samples should always be in their “final form exactly as they are ultimately presented to the end-user scanner. If they are shrink wrapped in final form, they should be shrink wrapped when they are verified. If they are inserted into a plastic case, they should be in the plastic case when verified. If they are on translucent plastic bottles with a colored liquid inside, they should be verified accordingly.

The process is every bit as important as the verification device itself. The verifier should be an ANSI/ISO compliant device. It is meaningless to use a quality testing tool with an unknown performance benchmark. And for the same reason, the verifier should be recently calibrated.