# Living with ISO-13660: Pleasures and Perils

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## Abstract

A first-of-its-kind print quality standard is about to be issued. ISO-13660 is intended as a practical, objective means of communication about basic image quality parameters and provides measurement methods that lend themselves to automation. Though much work remains to be done before it can be considered definitive, ISO-13660 represents a tremendous advance, laying out the first world-wide industry standard for digital print quality. On-going research and future technological developments can be expected to help flesh it out. Already, intensive day-to-day use of ISO-13660 has shown both its considerable strengths and some of its limitations, pointing the way to some significant enhancements. This paper exemplifies the use of ISO-13660 for measuring print quality in real-world applications, from print engine development to media benchmarking. The strengths of the standard, such as its dynamic threshold-setting technique, are demonstrated. Techniques like this one make the difference between robust, meaningful measurements and results with only comparative value limited to particular measurement systems. Some of the limitations of the standard will also be discussed, for example, difficulty in finding the 10% and 90% reflectance thresholds reliably, and weaknesses in the definitions of raggedness, graininess and mottle. Suggested changes to the measurement protocols are proposed for overcoming such limitations.


## Introduction

Over the past few decades, there has been a virtual explosion in printing and copying technologies, particularly digital technologies. These developments have forced many people in the printing/printer business to ask some basic questions about how to specify and assess print quality (PQ) in a consistent way that is not dependent on the specific printing technology they are using. Aside from color measurement equipment (spectrophotometers) and densitometers, there have been relatively few objective means of evaluating PQ of lines, text, print uniformity, registration, etc.

To turn this situation around, two things have been needed: 1) the development of international PQ standards and 2) implementation of standards in automated measurement equipment. Either of these things alone would be of limited value. But both together would represent a real advance for the printing/printer industry. PQ measurement equipment employing proprietary algorithms has been available for some years. But this has not proved to be particularly useful even within organizations, because PQ information could not easily be conveyed by one business partner, for example, to another with different equipment. At the same time, international standards for print quality are of limited use unless they are implemented in automated equipment that can perform the high volumes of measurements typically required. The history of spectrophotometer and scanning spectrophotometer use offers an analogy. Initially, spectrophotometers served well for spot-checking color, but now many people in the color printer business use scanning spectrophotometers so that a higher volume of measurements can be made.

Combining international standards and automated measurement is an important enabler for many aspects of the printing/printer business. For R&D it provides a valuable tool for measuring progress in printer development. For production, it provides a consistent means of monitoring the quality of products prior to shipment. For incoming inspection, it is a tool for determining the quality of printer components such as heads, inks, and media. For purchasers of printed material, it is a tool for writing objective print quality performance specifications and resolving printing quality disputes. [1] Basing PQ measurements on international standards allows attention to focus on actually improving print quality, rather than arguing about measurement methods.

Developed over the last few years and soon to be issued,[1,2] the new ISO-13660 international print quality standard is well suited to automated print quality measurement. The standard has been implemented in commercially-available automated PQ measurement instruments for the last year and a half. The authors' experience using the standard for automated PQ analysis during this time has shown both the value of the standard and some of its limitations. This paper will briefly describe the standard, its strengths and limitations, and some sample applications.

## ISO-13660

ISO-13660 is the first international standard to incorporate a wide range of print quality attributes. The purpose of the standard is to define procedures and algorithms for quantifying basic print quality attributes, as shown in Table 1. Character and line attributes defined include blurriness, raggedness, line width, character darkness, contrast, fill, and extraneous marks and background haze in the character field. Large area attributes defined include large area darkness and background haze, graininess and mottle, extraneous background marks, and voids. Together, the fourteen attributes defined in ISO-13660 provide the tools for solving many PQ problems. The measurement procedures used are intended to be simple and unambiguous and to lend themselves to automation. The standard is intended for black and white prints on paper, though it is clearly extensible to color. Detailed descriptions of the PQ attributes and measurement methods are available in the standard itself[3] and in other literature.[1,2]

*Table 1: ISO PQ Attributes*

| Character and Line |
|---|
| ❶ Blurriness |
| ❷ Raggedness |
| ❸ Line width |
| ❹ Darkness, character |
| ❺ Contrast |
| ❻ Fill |
| ❼ Extraneous marks, character field |
| ❽ Background haze, character field |

| Large Area |
|---|
| ❶ Darkness, large area |
| ❷ Background Haze |
| ❸ Graininess |
| ❹ Mottle |
| ❺ Extraneous marks, background |
| ❻ Voids |

The standard is device independent – the image measured can be a laser print, an inkjet print, a pencil drawing, etc. Intended for text and graphics, the measurements specified can be made on any character (text), line, or large area. Thus, no specific test images are required. The standard does not require a specific measurement device, but sets forth compliance requirements for the device.

The standard leaves setting acceptance criteria to the user. Once PQ measurements have been made, it is up to those involved to determine if the print quality is acceptable.

## Implementation of ISO-13660

ISO-13660 assumes that the image to be analyzed will be acquired digitally. This can be done with a flatbed scanner, a microdensitometer, or a CCD camera with a digitizer. Any device may be used as long as it is capable of digitizing the image at a minimum of 600 dpi (dots per inch) and passing certain calibration compliance tests.

The choice of image acquisition device is controlled by a number of trade-offs. Scanners of the flatbed 600 dpi variety offer the advantage of low cost and can easily acquire the entire page area. However, these scanners tend to lack the resolution needed for accurately measuring certain line attributes such as raggedness. Microdensitometers are very accurate high-resolution devices but tend to be expensive and slow. A CCD camera-based system has a combination of features especially well suited to PQ analysis. The resolution can be very high, 300,000 to 2,000,000 pixels can be acquired in a single frame, and the cost is reasonably low. Since a CCD camera-based system typically captures only a small section of the printed page at a time, coupling the camera to an automated motion stage is generally necessary.

The first commercially available PQ analysis system to incorporate the ISO-13660 standard was developed by QEA, Inc.[4] The system, typically configured with a CCD camera, is illustrated in Fig. 1. It includes a vacuum-equipped X-Y motion stage for positioning and holding samples.

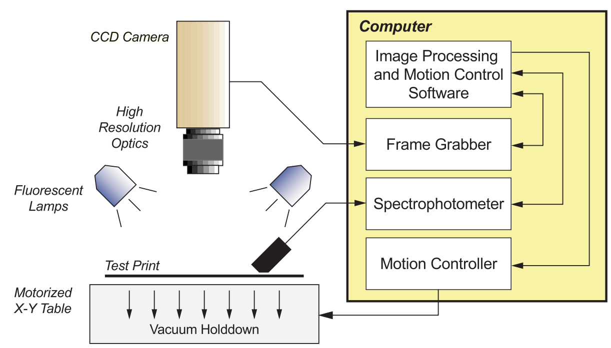


*Figure 1 :Schematic representation of QEA's IAS-1000 Automated Image Analysis System*

## Strengths of ISO-13660

It is notoriously difficult to get a group of people from different organizations to agree on PQ analysis methods. For this reason, the ISO-13660 standards committee sought consensus on those PQ attributes that could most easily be agreed upon. They wanted to establish a starting point from which a more comprehensive standard could be developed, intending that PQ attributes would be added later as agreement on methods was reached. This has proved to be a fruitful approach.

Several aspects of the standard are noteworthy, but two in particular could substantially change the world of print quality measurement.

The first of these is the standardization of PQ measurement methods. Over the years, since standardized methods have been unavailable, researchers have developed many disparate methods for measuring PQ attributes.

Inevitably, this has meant that much discussion has focused on defining attributes and defending measurement techniques rather than on solving product performance problems. With widespread adoption, ISO-13660 will give the printing industry a shared terminology and methodology, shifting the focus to more productive issues.

The second key aspect of ISO-13660 is the requirement that a PQ evaluation system use calibrated spatial and density units, e.g. length and distance in µm and density in percent reflectance. Today, some scanner- and camera-based systems output data in uncalibrated units such as pixels and GSV (gray scale value – e.g., 0 to 255) units. But using uncalibrated units means that data from one system cannot be compared with data from another, and repeatability is often poor. Using calibrated units is fundamental to communicable print quality analysis: data from different systems can be compared and repeatability is greatly improved.

Some of the ISO-13660 methodologies are especially noteworthy. The technique for measuring line width is a good illustration. The standard defines the reflectance of the substrate (white) and the colorant (black) to be $R_{max}$ and $R_{min}$, respectively. The edge contours of the line are defined as the point of 60% transition between $R_{max}$ and $R_{min}$, as given in this equation:

$$R_{60} = R_{max} - 60\% \, (R_{max} - R_{min})$$

Similarly, edge sharpness is based on the 90% and 10% inner and outer boundary edges. $R_{90}$ and $R_{10}$ are derived by the method shown above. This approach is effectively an adaptive edge thresholding technique and is very robust to variations in the paper brightness or ink darkness.

ISO-13660 offers other advantages. Its measurement procedures are simple, generally well defined, and easily understood. Our intensive use of the draft standard during the last year and a half has shown that the fourteen PQ attributes already defined are applicable to solving a wide range of print quality problems.

## Limitations of ISO-13660

Clearly, ISO-13660 already embodies many well worked out techniques. However, it is through widespread use that the standard will be refined and enhanced over time, and with this in mind a few limitations should be pointed out.

The definition of raggedness appears to be incomplete in two respects: neither limits on the fineness of the sampling nor the maximum length of the line segment sampled is specified.

The standard stipulates sampling of at least 23.6 dots per mm (600 dpi) or one sample every 42.3 µm, but imposes no limit on how finely the edge can be sampled. This presents a problem, because finer sampling can result in higher raggedness values, even though raggedness at these wavelengths has low perceptability.[5] This point has been illustrated by Grice and Allebach[6] and could prove to be a serious limitation to the value of the raggedness PQ attribute unless the standard is improved. The standard should require that the data be filtered to closely approximate a 600 dpi edge sampling.

The standard calls for the lines sampled to be at least 1.25 mm long but gives no upper limit. This too can pose a problem since longer lines, e.g. 10 mm, generally have some curvature that tends to dominate the raggedness value. Two sets of results, one derived from a 1.25 mm sample and the other from a 10 mm sample may be quite different even if the raggedness is discernibly the same. The standard should require either a fixed measurement length, or it should specify a high pass filter to be applied to the tangential edge profile. For now, users should report the measurement length along with the raggedness values.

Line edge blurriness measurement is another area needing refinement. Blurriness is defined in the standard as the distance between the $R_{10}$ and $R_{90}$ thresholds. Our experience has been that because the $R_{10}$ threshold is typically in a region of low slope in the reflectance profile it tends to have poor repeatability. In contrast, the $R_{20}$ threshold generally occurs in a region of sharper transition in the profile and appears to give more reliable results.

There is also room for improvement in ISO-13660's graininess and mottle methods. The standard defines graininess as non-uniformity occurring on a scale less than 1.27 mm but greater than 42.3 µm and mottle as occurring on a scale greater than 1.27 mm. This fixed size cutoff between graininess and mottle has the advantage of simplicity but makes measurements relatively insensitive to certain PQ problems such as ink coalescence in inkjet printing.[7] We have found that an alternative approach of using variable tile sizes can reveal important detail about the size scale of non-uniformities. When using variable tile sizes, the tile size used in the analysis must be reported with the results.

A number of PQ attributes would also be valuable additions to the standard. Some of these are likely to be included in future ISO-13660 addenda.[1,2]

A definition of line position, for example, would be helpful. Line position is used extensively in diagnostic PQ measurements such as determining the straightness of inkjet nozzles.[8]

Also helpful would be a definition of banding. Banding is a significant problem in most printing processes, occurring in both periodic (sinusoidal) and non-periodic (impulse) modes.[9] Defined PQ attributes for both would be very advantageous. SC28, the ISO sub-committee that produced ISO-13660, has a specific work item (N348) for developing this as an extension to 13660.

In addition, a logical extension of ISO-13660 would be the inclusion of color measurements such as intercolor bleed, and color registration and image noise (non-uniformity) in halftones. The SC28 committee is working with a current proposal to extend 13660 to large area color measurements.

## Application of ISO-13660

The value of a PQ standard is borne out in its application, as illustrated in some recent studies.[6]

In the world of inkjet printing it is well known that media type significantly impacts print quality, as discussed in the literature. [10] In the following example, a commercially available desktop inkjet printer was used to test raggedness values on six types of inkjet media. The measured raggedness values, based on the ISO-13660 definition, showed marked differences among the different media types, as seen in Fig. 2. The plain paper produced average edge raggedness as great as 20 µm whereas glossy film produced raggedness of only about 8 µm.

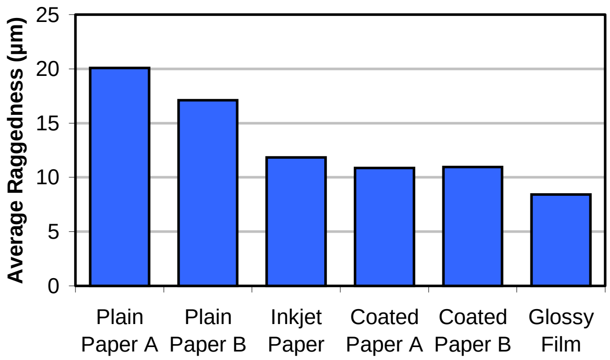


***Figure 2**: Average line edge raggedness measured on different inkjet media samples (line length = 4mm, low-pass filtered at 42µm)*

With further analysis of the data, it was determined that the raggedness of the lines was highly correlated to line orientation, horizontal vs. vertical, as shown in Fig. 3. There was little apparent media effect in the vertical lines. The media effect in the horizontal lines, however, was pronounced, ranging from 22 µm on plain paper to 1.5 µm on glossy film. The disparity in edge raggedness between horizontal and vertical lines was traceable to poor dot placement by the inkjet printer, as shown in Fig. 4, which masked the media effect in the vertical lines.

Thus, applying ISO-13660 contributed not only to an analysis of ink-media effects but also to exposing a printer performance problem.

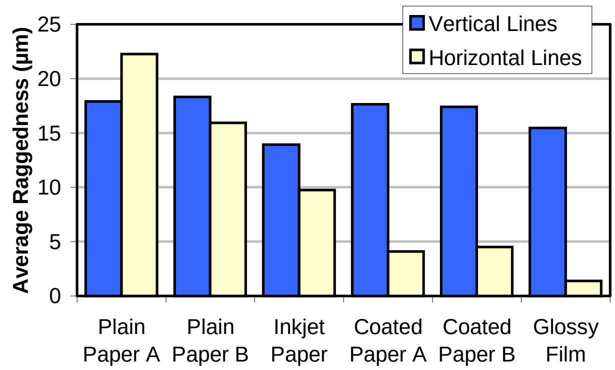


***Figure 3**: Effect of line orientation on line edge raggedness (line length = 4 mm, low-pass filtered at 42 µm)*

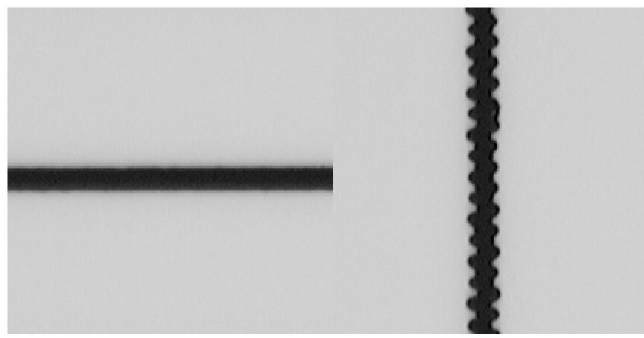

*Figure 4: Horizontal (left) and vertical (right) black lines printed on glossy film. Image size is 4.4×2.2 mm*

Raggedness is one measure of the amount of wicking (or bleeding) that occurs when inkjet ink hits the media surface. Another measure of bleed is line width. When ink is laid down on the paper in the shape of a line, bleeding tends to make the line wider. This effect is shown in Figure 5 for a black line with a nominal width of 1 mm. Generally the plain paper produces more bleed (wider lines) than the coated papers. This increased bleeding is effectively a loss of resolution.

A phenomenon related to bleed is intercolor bleed. This occurs when inks of different colors are laid down next to each other and one color wicks into the other. Figure 5 shows intercolor bleed of a black line printed on a field of yellow ink. As the figure shows, intercolor bleed (black/yellow) is generally greater than bleed (black ink on white media). One important exception to this is the glossy film sample. On this sample, the bleed and intercolor bleed values are almost the same. While intercolor bleed is not specifically defined in ISO-13660, the line width measurement technique defined in the standard is essential for analyzing this phenomenon.

A tremendous amount of information was generated in the investigations described. However, in the absence of communicable standards these results would not necessarily be meaningful beyond the limits of the study.

Raggedness is a basic attribute – but exactly what is it? ISO-13660 spells it out: raggedness is the geometric distortion of an edge from its ideal position. It is measured as the standard deviation of the residuals from a line fitted to the edge threshold of the line under study, calculated perpendicular to the fitted line. The definition provides a meaningful terminology for discussion, and the measurement method ensures that the data can be communicated. With refinements such as those suggested above – i.e., a limit on the fineness of the sampling and an upper bound on the sample length – the technique will become very robust.

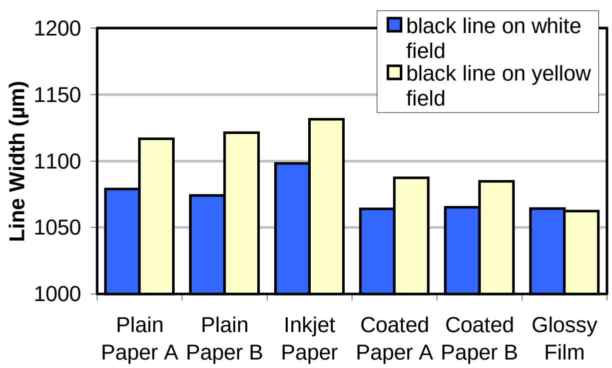


*Figure 5: Line width measurements. 1 mm black lines on white media are used to characterize ink-to-media bleed. 1 mm black lines on a yellow field are used to characterize intercolor bleed.*

Further, ISO-13660's requirement that instruments be calibrated to physical units has been shown in recent studies to be critical for ensuring reproducible results. When uncalibrated (e.g., GSV) units are used, the same test conditions can give rise to significant measurement discrepancies, due to such factors as variations in media brightness or the aperture setting in the optics. This can have major ramifications for printing product manufacturers. With instruments calibrated to physical units, results such as those shown in Figs. 2 and 3 can be taken at face value and used as a reliable basis for making decisions.

## Conclusions

The need for a universal print quality standard has been felt in the printing industry for a long time. Without a standard, questions can be raised about every aspect of a PQ measurement, from the definition of the attribute to the measurement techniques and instrumentation used. ISO-13660, the new international standard for print quality evaluation is about to be released and promises to shift the focus of debate to product performance, where it belongs.

The standard defines fourteen PQ attributes and specifies techniques for measuring them. As the most comprehensive available standard of its kind to date, it promises major benefits to all aspects of the printing industry, from basic research to marketing, by providing a framework for communication industry-wide. In its current state, the standard represents a critical first step. Enhancements and additions will follow as the standard is widely adopted and applied.

Widespread adoption, however, depends on its general availability in PQ analysis systems used by the industry. In another important first step, ISO-13660 has been incorporated into the software of a commercially available automated PQ analysis system. Intensive use of this system to study a wide diversity of applications has amply demonstrated the importance of ISO-13660 for ensuring that studies of printing products are well controlled and communicable.

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## Biography

Dr. John C. Briggs joined QEA in January 1998. He is responsible for new product development and pre-sales customer support. Previously at Iomega Corporation, he was a key contributor to the design and development of the Zip™ drive. Dr. Briggs holds six patents and has several patents pending. Between 1986 and 1991, he received his BS, MS, and Ph.D degrees in Mechanical Engineering from the Massachusetts Institute of Technology. His research focused primarily on non-destructive testing and acoustic emission measurements.