Measuring customer perception of print quality

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The quality of printed text was perceived to be higher for lithography than for gravure.

Paper has a significant effect on the quality of the printed image. Different paper properties affect diverse printing technologies in various ways (*1-4*). Optical properties, particularly the paper spread function and paper scattering, influence image quality for all printing technologies. With the ink-jet printing process, for example, both scattering and liquid absorption can dramatically affect color-print quality (*5, 6*).

Unambiguous description of print quality is a complex problem whose solution has eluded image scientists for some time. To simplify the understanding and implementation of print quality, we have proposed a step-by-step approach called the "image quality circle" (IQC) (*7*).

Image quality circle

Elements

The goal of any papermaker, or for that matter anyone involved in imaging systems or materials, is to relate the technology variables associated with the paper to the customer quality preferences. **Figure 1** shows this fundamental objective via the large arrow. The link between customer preference and papermaking variables is typically determined by varying a paper parameter, printing images on the resultant paper, and then asking customers to judge the quality of the printed image. This clearly works, but it is inefficient because the customer must render a new judgment every time a paper parameter is changed. The IQC breaks down this relationship into a series of definable steps. The four elements of the IQC are depicted as rounded rectangles in Fig. 1.

Customer quality preferences. The goal of the IQC is to relate the customer image-quality preference to perceptual elements of image quality in some quantitative manner.

Customer perceptions. The major perceptual components of image quality are sharpness, graininess, lightness (tone reproduction), and the raggedness of characters.

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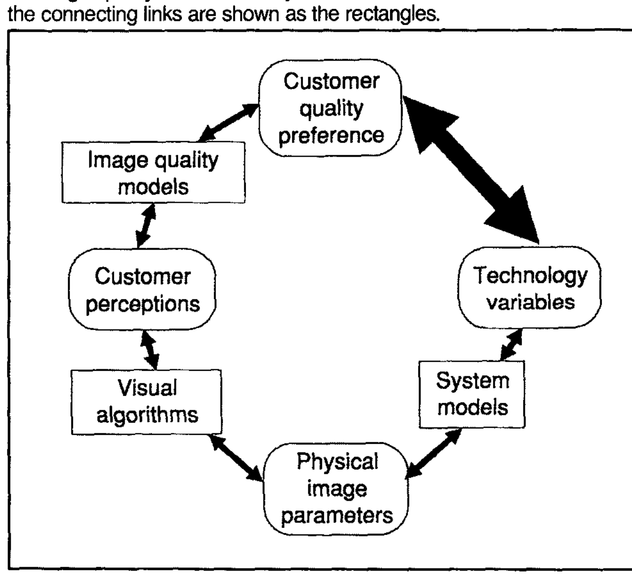
1. Image quality circle. The key elements are the rounded boxes, and the connecting links are shown as the rectangles.



Physical image parameters. Physical image parameters are the quantitative functions and parameters we normally ascribe to image quality: modulation transfer function, Wiener spectra, resolution, etc. From a historical perspective, these are considered to be objective measures of image quality.

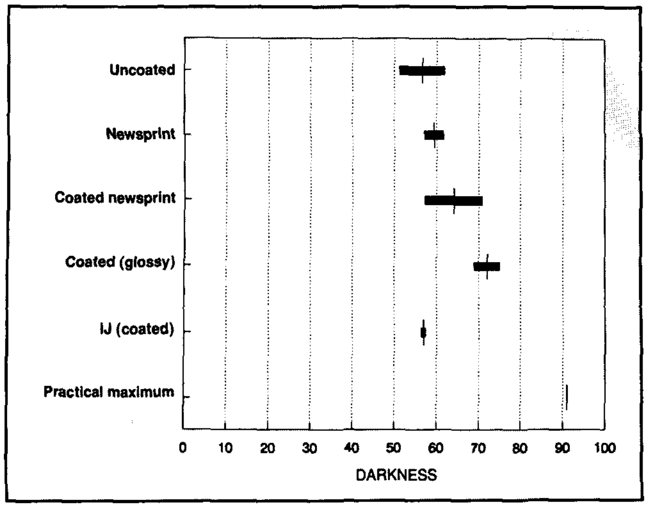
Technology variables. Technology variables are the elements that the papermaker manipulates to produce a sheet that is optimized for a particular imaging or printing technology. Such variables include fiber size, filler composition, and smoothness.

Connecting links

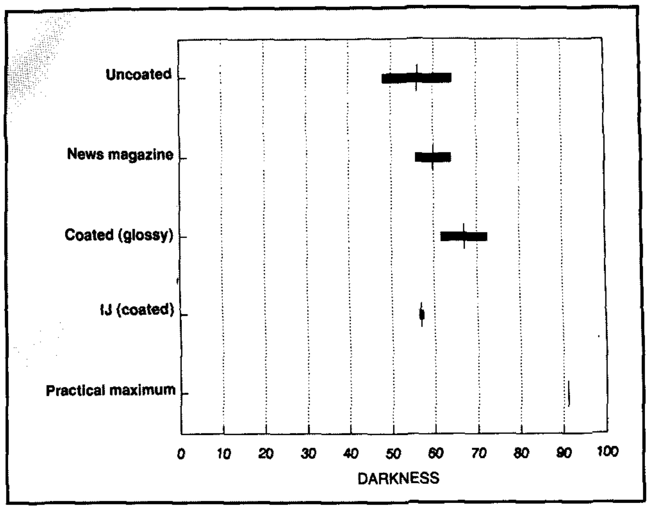
The four elements of the IQC are linked to one another via three models, or algorithms, which are depicted as rectangles in Fig. 1.

Image-quality models. Image-quality models are empirical models that relate the customer percepts—sharpness, graininess, lightness, raggedness—to image quality. It describes in mathematical terms the tradeoff

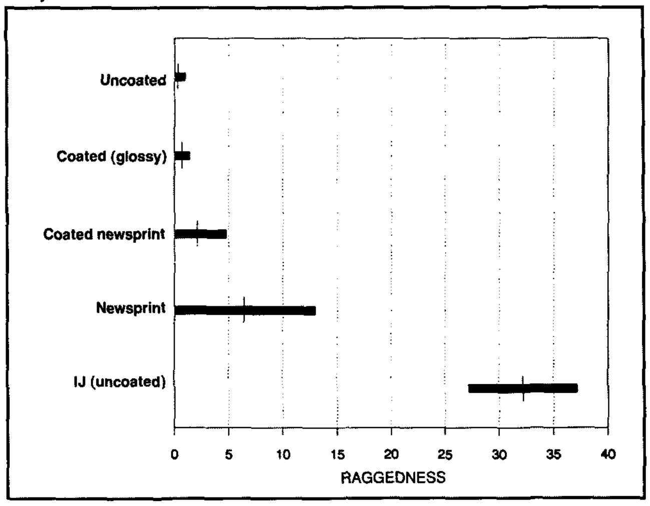
2. Measured darkness of lithographic prints for various paper grades. The width of each bar represents standard deviation ($\pm 1\sigma$), while the vertical line represents the average darkness for each paper grade. The value for ink-jet (IJ), a nonimpact printing process, is included as a reference.



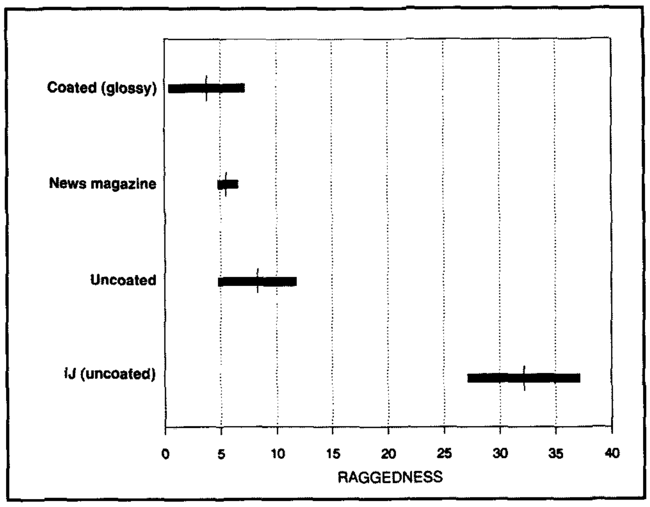
3. Measured darkness of gravure prints for various paper grades. The practical maximum of 92 cannot generally be exceeded by ink-on-paper printing technologies.



4. Measured raggedness of lithographic prints for various paper grades. Ink-jet value is included as a reference.



5. Measured raggedness of gravure prints for various paper grades.



that the customer makes when judging image quality.

Visual algorithms. Visually based algorithms have a long history in photographic image quality. We attempt to find the recipe (algorithm) that can be used to compute a percept, e.g., sharpness, from something that we can measure, e.g., the gradient of a printed edge. In the context of the IQC, "visually based" means that the spatial properties and the nonlinear stimulus-response aspects of the human visual system are overtly taken into account in the algorithm. Algorithms abound in the literature, so there is a fertile field to choose from.

System models. System models are the analytical models that predict the physical image parameters from the technological variables. One example might be the model for a Fourier spectrum (amplitude spectrum) of a line boundary for a dot-matrix printer using knowledge of the dot diameter and the dot spacing (*8*).

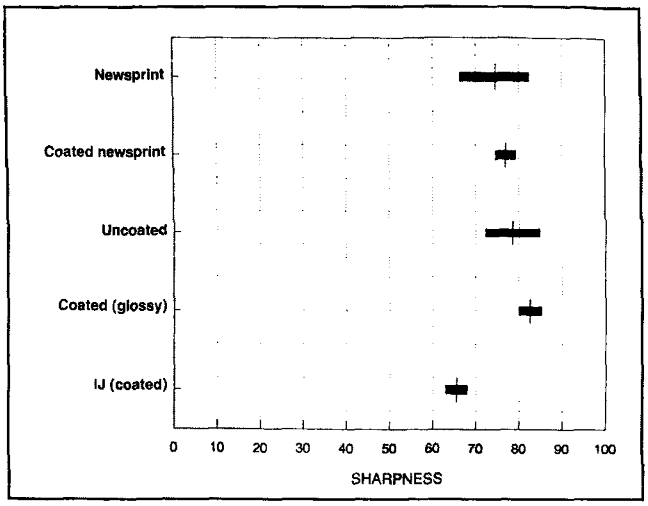
Application

The IQC breaks the complex problem of relating customer print-quality preference to the technological variables associated with paper into a series of definable components. It is not necessary for all of the IQC's components, or elements, to be in place for the concept to be useful. Currently, we have been focusing our efforts on the development of visual algorithms that relate physical image parameters to the customer perceptions of printed text images.

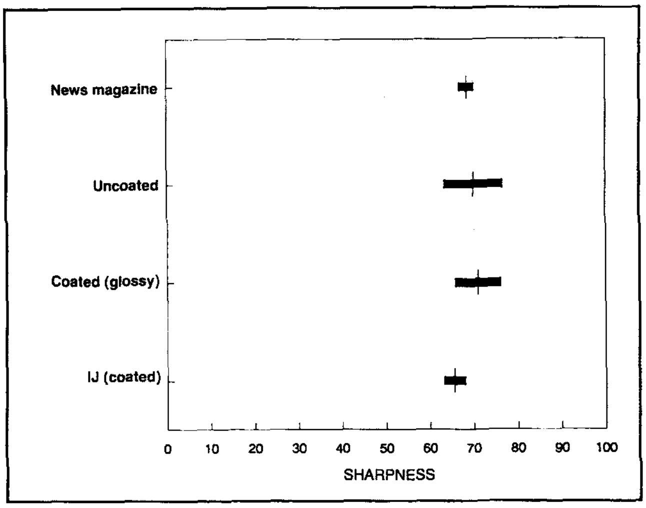
Analysis of gravure and lithography

An important consideration in selecting paper for any printing processes is the influence of paper grade on print quality. Thus it would be useful to distinguish the effects of various papers on print quality. A full-scale analysis

6. Measured sharpness of lithographic prints for various paper grades. Ink-jet value is included as a reference.



7. Measured sharpness of gravure prints for various paper grades.



of print quality is beyond the scope of this article. However, we can illustrate the IQC approach by focusing on a segment of the circle in Fig. 1. This segment comprises customer perceptions, visual algorithms, and physical image parameters. Our goal is to discover, for a given printing process, if we can measure differences in customer perceptions resulting from differences in paper grades.

Customer perceptions

There are three key customer perceptions, or attributes, that govern printed text quality: the darkness of the characters, raggedness of edges or boundaries of the text, and the sharpness. In our scaling studies and in our Image Quality Surveyor™, we have used the following definitions:

Character darkness. Character darkness is how gray or black the characters appear. A high value of darkness means the characters are very black.

Character raggedness. Character raggedness is the variation in the boundary of a character. A completely smooth character would have a raggedness value of zero.

Character sharpness. Character sharpness is the distinctness of transition of the character boundary from white to black. A high value of sharpness means the characters are very sharp. A low value means the characters lack sharpness or are blurry.

Samples

Samples of printed matter used for this study represent the spectrum of printed products that an office worker might come in contact with, either at the office or at home. They range from newspapers and magazines to the glut of printed material that is commonly referred to as "junk mail." The samples were sorted according to the printing method used, either lithography or gravure. Samples within each of the printing categories were further subdivided, roughly according to the type of paper used, to discover possible paper influences on several customer perceptions of print quality.

Measurements

The first step is to measure the physical image parameters of the selected samples using machine-vision technology. Physical image parameters comprise such characteristics as line profile, the Fourier transform of the character line edge derivative, and the Fourier transform of the character boundary variation. Five samples of each paper and printing process were selected for measurements. In all cases, vertical characters or lines were measured so the data would be comparable.

After completing these measurements, we determine the customer-perception rating based on algorithms relating these percepts to the physical image parameters. The algorithms have been developed by having people perform visual scaling experiments on a wide range of printed samples. All of our algorithms include the characteristics of the human visual system in some form to assure robustness of the calculated rating.

Results and discussion

Darkness

Darkness is measured over a scale of 0–100. A value of zero is a perfect white, while a value of 100 is a perfect black. The darkness results for the lithographic samples are shown in **Fig. 2.** The vertical bar represents the mean value, while the width of the rectangle indicates $\pm 1\sigma$ (one standard deviation). An ink-jet reference point, on coated paper, is included because print quality with this technology is heavily dependent on paper characteristics.

The darkness results for gravure are shown in **Fig. 3**, with ink-jet results for comparison. Figures 2 and 3 also include the practical maximum darkness for images on paper, which is about 92. Comparison of Figs. 2 and 3 shows that lithography generally produces darker images than gravure for almost all paper categories. It is no surprise that coated papers produce higher darkness levels than uncoated papers.

Darkness is one of the key components of print quality.

Our measurements confirm that darker, higher-quality images generally are produced by lithography on coated paper. However, in the absence of data regarding preferred darkness vs. application, it is not possible to determine the adequacy of combinations of printing technology and paper.

Raggedness

The raggedness scale is open-ended, i.e., any value greater than zero is possible, and there is no upper limit. **Figure 4** illustrates the raggedness for lithography as a function of the paper type, while **Fig. 5** illustrates the results for gravure. An ink-jet reference on uncoated paper also is presented in both figures.

Figures 4 and 5 illustrate that gravure has higher raggedness than lithography. This result should be no surprise, because gravure uses a halftone screen for both text and pictures, while lithography does not. The high value of raggedness for ink-jet printing is largely due to the dot-formed nature of ink-jet images and the wicking of ink between the fibers. Raggedness values less than about five are probably of no practical consequence, while higher values will contribute to a loss in print quality.

Sharpness

Our sharpness scale has a range of 0–100. A value of 100 represents "perfect" sharpness. No higher value is possible. Sharpness values of zero are judged to be very blurry and not ordinarily useful.

Figure 6 presents the sharpness results for the litho, and **Fig. 7** shows the data for gravure. Again, the results indicate that lithography yields sharper images, pretty much independent of the paper, when compared with gravure. Most litho images have sharpness numbers greater than 75, with values for gravure tending to be in the 60s.

Summary

The results of this analysis show that there are clear trends in perceived darkness, raggedness, and sharpness of text printed by lithography and gravure and that these differences are dependent on paper grade. The data indicate that customer-perception ratings are more favorable for lithography than for gravure. We find that, for either printing process, better paper grades yield higher values of customer-perception ratings than lower paper grades. However, an image-quality model would be required to explicitly elucidate customer quality preferences for the measured combinations of darkness, raggedness, and sharpness.□

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