Numerical evaluation of the printability of paper surfaces

By R. Danby and H. Zhou

Abstract: This paper describes a technique that numerically defines the print quality potential of a sheet of paper through density measurements BEFORE it is shipped, by measurement of the micro-density of the sheet.

The technique can be used to quantify the differences between two sides of a sheet of paper, between batches produced at different times on the same machine or to compare the same grade from different sources.

Previous papers (1 & 2) have shown that the final print quality of a sheet of paper is dependent on the surface density variations of the sheet, which in turn directly affects the absorption of the printing ink into the sheet. Using the Image Analysis techniques (3) devised for measuring density differences of the sheet, a computer program was developed in which these numbers could be used to simulate the absorption rate of printing ink into the sheet, corresponding to the micro-density differences for a four color printing process. Results correlated well with those obtained on the commercial printing press. The quality of both the commercial and the computer simulated printed samples, however, was evaluated by visual assessment only, which is open to variations in judgement and personal preferences.

Using the numeric values from the AstenJohnson computer image analysis system and following an approach similar to those outlined for the "Robotest Paperlab 1 Formation Tester" (4), values have been developed and are termed Paper/Print Quality Index (PQI), Floc Index and Void Index. The values are similar to those demonstrated by the Paperlab tester but are obtained using a different methods. They can now be used to numerically assess the paper quality BEFORE shipping and printing.

The Paper/Print Quality Index (PQI) is a measure of sheet density, attained by capturing light which has been transmitted through a sheet of paper. This measurement is used in calculations to assign numbers to sheet density uniformity, which will accurately predict final print quality for print gloss uniformity, mottle, print through and set off. The numbers cannot be used to predict skip dot values on rotogravure because this feature is influenced by surface smoothness.

The technique uses both split sheets for twin wire formers and whole sheets produced on Fourdrinier to generate a numeric rating for Paper/Print Quality Index, Floc Index and Void Index.

The highest level of print quality will be achieved on a sheet having a high Print Quality Index (PQI) (maximum 122), and very low Floc and Void Index numbers.

Examples provided use this evaluation technique and are also used to compare commercial printing results.

The measurements of sheet density fall into the following three categories:

- **Paper/Print Quality Index** - is a characterization of the uniformity of the sheet image. It is calculated from the average gray scale level. This is the level at which the printer optimizes his printing conditions, such as inking level, ink viscosity and printing pressure, in order to achieve the best results for that sheet. The range of Paper/Print Quality Index is from 20 to 122. The higher the PQI value, the better will be the final print quality.

- **Floc Index** - represents the total pixels that have a lower gray level than the mean value (high sheet density). This number is an indication of the level of offsetting and mottle that may occur due to a lower level of absorption of printing ink into the sheet caused by the higher sheet density. The lower the Floc Index, the better will be the overall print quality.

- **Void Index** - represents the total pixels that have a lower gray scale value than the mean value (lower sheet density). This number is an indication of the level of strike-through of printing ink to the opposite side of the sheet caused by high absorption of ink into the sheet due to the lower sheet density. The lower the Void Index, the better will be the print quality.

**Image Analysis System**

Both Twin Wire and Fourdrinier sheets can be analyzed with this method. Twin Wire sheets are split into two, using the laminator technique, so that the density differences on each half can be evaluated. The outside surface of each portion of the split sheet is placed on the light box with the outer surface closest to the camera. In the case of Fourdrinier sheets, which will not split, images are taken with each surface closest to the camera. In both cases an image is produced that represents the density differences on the sheet surface receiving the printing ink.

The sheet of paper is illuminated (using a cold cathode light box) by passing light through the sheet to highlight sheet density differences. The image is captured via a CCD camera and lens system, digitized with a frame grabber board and processed with image analysis software on a computer.
Observation of the two transmitted light images in Figure 1 indicates that sheet ‘A’ is very uniform compared to sheet ‘B’. The Paper/Print Index numbers quantify the difference between these two sheets.

5X5 PIXEL AVERAGING FILTER
Figure 2 shows the result of applying the 5x5 Pixel filter to the original images shown in Figure 1. The smaller details of the sheet have been obscured but the overall sheet quality variation has been retained. The averaging is necessary not only to reduce the calculations involved, but also to help account for the spreading of ink on the surface of the sheet.

Paper/Print Quality Index
Figure 3 compares the 64 bin gray level pixel histograms of the smoothed images. The good sheet, on the left, has a very narrow distribution of gray levels, with almost all pixels falling within the 3 center bins. In contrast, the poor sheet has a much broader distribution and the 3 center bins of pixels account for only a small portion of the total.

Floc and Void Analysis
The Floc and Void images shown in Figure 4 highlight the differences between the two sheets. It can be seen that the uniform sheet has many floc/void areas but they are small and account for only a small portion of the total sheet area. Although the non-uniform sheet has fewer floc/void areas, they are large and account for a significant portion of the sheet area.

The Floc Analysis data shown in Table 1 reflects the visual analysis in greater detail. The contents of this table highlight the key numeric differences between the two sheets.

The Void images shown in Figure 4 are reverse images — refer to the following section “Void Index Comparison” for explanation.

SPLIT SHEET EVALUATION OF TWO BEL BAIE SHEET SAMPLES
The images shown in Figure 5 represent two split sheets formed on Bel Baie formers in the same paper mill, using essentially the same stock. The Paper/Print Quality Index numbers show the considerable difference that can be observed between the top and bottom surfaces of #1 machine while #3 machine is closer to being a uniform sided sheet. The two top surfaces are visually different, yet the PQI numbers are close. This example demonstrates the advantages of the numerical comparison based on measurement of
sheet density, rather than relying on a visual comparison only.

**Floc Index Comparison**  
Figure 6 shows the Floc image comparison of the same Bel Baie sheets shown in Figure 5, highlighting the differences in structure of these two sheets, and both sides of each sheet. The top two images show a difference in the floc shapes and sizes, yet the Floc Index numbers show that the total area covered by the heavier flocs is about the same for both top surfaces.  
These images point out the areas in the sheet that will cause offsetting and mottle due to a lower level of absorption of printing ink into the sheet at these points of higher sheet density.

The bottom two Floc images show that there is a considerable difference between the two machines on the bottom or conveying wire side. This difference is reflected in the Floc Index numbers. The higher the Floc Index, the worse the Floc condition in the sheet. From the Floc index numbers below, we can expect that the print quality on the #1 bottom surface

**TABLE I. Numeric differences between uniform and non-uniform sheets.**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Uniform Sheet</th>
<th>Non-Uniform Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Floc Area</td>
<td>16.0</td>
<td>33.9</td>
</tr>
<tr>
<td>Largest Floc Size (mm²)</td>
<td>&lt;2.25</td>
<td>&lt;25.0</td>
</tr>
<tr>
<td>Total Void Area (%)</td>
<td>10.9</td>
<td>24.4</td>
</tr>
<tr>
<td>Largest Void Size (mm²)</td>
<td>&lt;0.50</td>
<td>&lt;9.0</td>
</tr>
</tbody>
</table>
his printing conditions for optimum print quality; and (3) The void or low density area where the printing ink will penetrate into the body of the sheet which may cause possible strike through to the opposite side.

Within the right hand enlarged image the rectangular outline of the individual pixels can be seen along the sloping edge of the letter ‘M’. These pixels can be seen at varying levels of gray intensity (0-255).

**Paper/Print Quality Index of a whole sheet compared to a split sheet**

The relatively close Void Index numbers four all four surfaces suggests that they will all have similar printing ink “strike through” potential.

**Evaluation of Computer Simulated Printed Sheet**

Figure 8 shows a computer simulated printed image at approximately 7X magnification on the left hand side and a further magnification on the right. Three distinct areas can be seen in the right hand image: (1) Flocs or high density areas where the ink is blacker than the surrounding areas due to the lower rate of absorption into the sheet, (the mottled area in printing terms); (2) The medium density area that represents the majority of the printed image. It is this average or mean area that represents the PQI, and it is this area that the printer uses to set up

...will not be as good as #3 bottom due to the higher level of Flocs causing mottle and possible set off in the areas of the heavy Flocs.

**Void Index Comparison**

Because the void areas are represented in our evaluation as light or white areas, the only way to represent them pictorially is to show a reverse image. Therefore the images shown in Figure 7 are shown as black and white, where black represents the very light areas in the sheet where the printing ink will have high absorption due to the lower density of the sheet, which is where strike-through may occur.

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PQI Evaluation of Commercially Printed Images.

Both of the sheets shown in Figure 10 were printed on the same commercial press, one roll behind the other, with no change in printing conditions. On Sheet A the facial features of the president of the United States of America are more clearly defined because the print quality is more uniform as a consequence of the sheet on which it was printed being more uniform. In the right hand image the continuity of the lines representing the facial features are interrupted by short sharp light areas in the sheet caused by wire mark and also light areas caused by areas around heavy flocs.

The top two images have been taken of unprinted areas from the same sheets. These images show the reasons for the difference in print quality. The numeric evaluation of the unprinted images also highlights the differences.

CONCLUSION

After extensive evaluation of the Paper/Print Quality Index testing method, it can be said that it provides a very useful tool to evaluate not only paper quality (formation), but also the final print quality that will be achieved on the printing press.

On numerous occasions it has now been successfully used to evaluate changes in either process conditions or paper machine clothing, especially forming fabrics. It has also been used on numerous printed samples to rate the quality of the paper from commercial printing.

Whole sheet formation as viewed or measured by conventional methods is only an average of the two sides, which can be very misleading. This work shows that formation when viewed through each of the two sides of a sheet after splitting is a true representation of each surface. The Paper/Print Quality Index is therefore a true representation of the printing potential of the two sides of any one sheet.

REFERENCES