A statistical study of dirt-count measurement system variation using optical-scanner-based image analysis

Douglas Hall and David J. Pruett

ABSTRACT: Optically-based systems have been introduced to replace traditional visual methods for quantifying the amount of finely divided ink particles that show up as visible specks in pulp. There is no standard method for evaluating the accuracy and precision of these new systems, but the authors present a general method for the quantitative comparison of two "dirt count" measurement systems. The variation in the measurement system was reduced significantly using a Hewlett Packard ScanJet IIc as the scanning device in place of the earlier ScanJet Plus scanner when both were operated at 300 dpi. Variation was further reduced when the ScanJet IIc was operated at 400-dpi resolution. The ScanJet IIc also provided better accuracy.

KEYWORDS: Accuracy, dirt count, evaluation, image analysis, measurement, optical scanners, precision, reclaimed fibers, reliability, standards, TAPPI, test methods, variations.

Kieffer Paper Mills, working in partnership with Kamyr Inc. and QualPro, recently started up a 100% deinked pulp mill in Brownstown, IN. In conjunction with this innovative approach in partnering, several other concepts, including self-directed teams and statistical process control, were used in the startup of the recycled pulp mill *(1, 2)*. The tools of continuous process improvement are being utilized to provide information on key quality measures of importance to the customer, on the measurement systems used in the mill, and on the process itself.

As the demand for higher-quality recycled pulp has increased, one of the most critical quality characteristics has become ink content. Finely dispersed ink particles show up in the pulp and finished paper as visible specks. "Dirt count" is a measure of the area in a sheet of paper that is made up of dirt particles rather than clean pulp fibers. In this context, "dirt" can mean anything that is not a clean paper fiber; for instance, ink, glue, or an actual particle of dirt or soil. Unfortunately, the dirt count of recycled pulp is one of the most difficult aspects to measure. While a TAPPI test method exists for dirt in pulp (T 213 om-89), the standard itself states, "The method rapidly loses precision as the dirt count increases. The precision is poor because of differences in operator judgement" *(3)*.

To improve upon the precision of T 213, the industry has begun using scanner based optical systems to detect and measure dirt. Kieffer utilizes an Optomax Speck Check Image Analysis System to determine dirt content. However, little has been published on how the accuracy and precision of this technology vary as it is pushed to its lower detection limits. Further, there is no standard method for evaluating the accuracy and precision of these new systems either on an absolute scale or relative to the TAPPI method. This paper describes a study undertaken to determine the variability of this measurement system when used in several possible configurations on recycled pulp with a very low dirt count. The methodology may be used to compare the accuracy and precision of this technology and instrumentation to other "dirt count" measurement systems.

Hall is mill manager, Blue Fiber Ltd. Partnership, 1620 Kearney St., Port Huron, MI 48060. When the article was written, he worked for Kieffer Paper Mills, Inc., 1220 W. Spring St., Brownstown, IN 47220. Pruett is a consultant, QualPro, P.O. Box 51984, Knoxville, TN 37950-1984.

I. Comparison of variation in dirt-count measurement using an Optomax Speck Check in various configurations

	Avg. ppm	*σ*	*UCL*	*LCL*	*% of Spec.*	*F*
ScanJet Plus (300 dpi resolution)	3.81	0.915	6.561	1.061	36.4	---
ScanJet IIc (300 dpi resolution)	2.52	0.312	3.456	1.584	12.5	8.60
ScanJet IIc (400 dpi resolution)	2.53	0.174	3.058	2.010	7.0	27.7

Experimental

Equipment

The Optomax Speck Check Paper Inspection System was evaluated using two different scanners: the Hewlett Packard ScanJet Plus and ScanJet IIc. Both of these systems have a 256-gray-level sensitivity. However, the maximum resolution of the ScanJet Plus is only 300 dots per inch (dpi), while the ScanJet IIc can reach a resolution of 400 dpi.

Calibration procedure

To set up the image analysis system and evaluate both its precision and accuracy, a sample with a known dirt count is needed. This can be used to determine the optical resolution and sensitivity settings needed to obtain results consistent with TAPPI method T 213. Unfortunately, no samples of Kieffer White River pulp, the product for which the dirt-count system was needed, exist that have a dirt count certified by an independent testing agency. Therefore, the optical system setup parameters were determined by round-robin testing of numerous handsheets with several customers. We found that the appropriate detection setting on the ScanJet Plus system at 300 dpi was 135, while the ScanJet IIc detection setting was 119 for both 300- and 400-dpi resolution. This parameter, which determines what level of gray the instrument perceives as "dirt," has a dramatic result on the reported dirt count, so it was critical that we and our customers determine settings that produced the same measurement when the same handsheet was examined using an optical system or TAPPI T 213. We have continued to circulate production standards to ensure consistent readings between the Optomax system in our laboratory and the TAPPI dirt counts obtained by our customers.

II. Comparison of dirt-count accuracy relative to the published value of the TAPPI Dirt Estimation Card using an Optomax Speck Check in various configurations

	Avg. ppm	*σ*	*Bias**
TAPPI Dirt Estimation Card (0.07–0.04 mm^2)	437.2	...	0.00
ScanJet Plus (300-dpi resolution)	468.5	40.37	31.27
ScanJet IIc (300-dpi resolution)	421.2	9.29	16.03
ScanJet IIc (400-dpi resolution)	457.9	1.61	20.67

*Bias = Absolute Value of Target (TAPPI Card) minus Actual.

III. Equations used to evaluate control limits

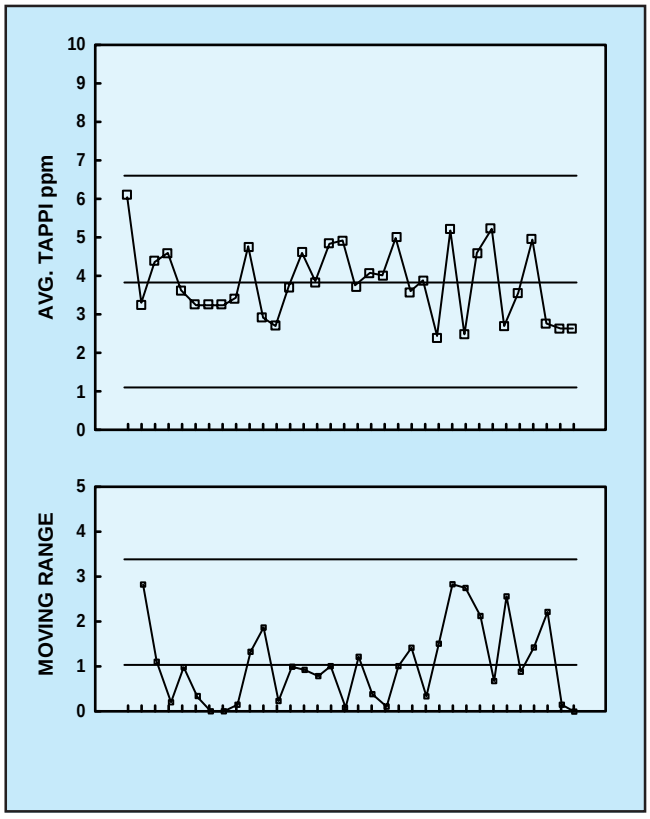
Chart	*Central line*	*Upper control limit*	*Lower control limit*
"Individual X"*	$\bar{X}$	$\bar{X} + 2.6M\bar{R}$	$\bar{X} - 2.6M\bar{R}$
Range	$\bar{R}$	$3.27\ \bar{R}$	0

*"Individual X" was an average of two readings taken consecutively for each determination.

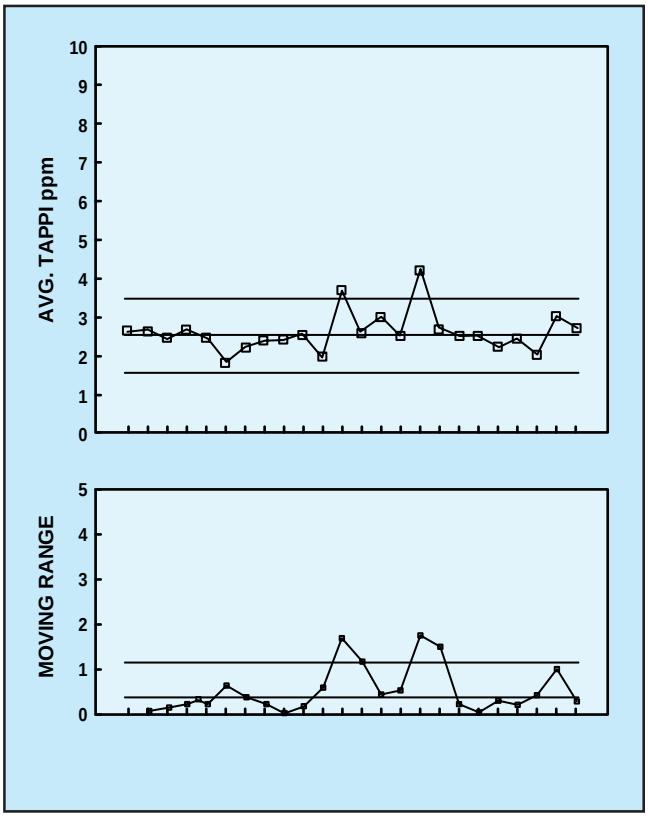
Precision study

The precision of the Optomax system using each of the two scanners was determined by establishing control charts for the system using the ScanJet Plus at 300 dpi and the ScanJet IIc at both 300 dpi and 400 dpi. A single handsheet was made following the TAPPI procedure, then laminated to protect it from contamination and wear. The dirt count of this standard handsheet was analyzed once or twice per shift for several days to determine how the reading varied over time. The analysis was performed twice each time and the two results averaged and treated as an individual data point to create individual X with moving range control charts. Except for the resolution setting on the ScanJet IIc,

1. Control chart for Optomax speck check using HP ScanJet Plus (300-dpi resolution)



2. Control chart for Optomax speck check using HP ScanJet IIc (300-dpi resolution)



which had to be toggled by software control between 300 dpi and 400 dpi to compare the results obtained at the two settings, all system parameters were locked for the duration of the test. The results of these measurements are shown in **Table I**.

Accuracy study

We also attempted to assess the accuracy of the Optomax system by utilizing the TAPPI Dirt Estimation Card *(3)* to provide particles of known area. Because of the arrangement of the printing on the TAPPI card, only the particle size range of 0.07 to 0.04 mm^2 could be used for the study. Three readings were taken using the same card and same field of view. The average parts per million and the standard deviation of the three readings were calculated for each scanner. The results of these measurements are shown in **Table II**.

Calculations

Control charts were created for each scanner, with two created for the ScanJet IIc to obtain information at 300 and 400 dpi. Averages, standard deviations ($\bar{R}/d_2$), and control limits were calculated to quantify the variability of each scanner system. Two additional calculations were also made:

$$\% \text{ of spec. consumed by meas.} = 100(6\sigma_{MS}/USL - LSL)$$

$$F = (\sigma^2_{larger}/\sigma^2_{smaller})$$

The percent of specification calculation is useful in quantifying how much of the specification range is consumed by the variation in the measurement system. The F statistic is a classical means of comparing the variances of two populations and determining if the variances are different *(4)*.

Control limits were calculated using the standard equations in **Table III**.

Results and analysis

The control chart of dirt count of the "standard" handsheet in parts per million for the ScanJet Plus system is shown in **Fig. 1**. (All control charts in this paper are displayed on the same scale to facilitate comparison.) The average dirt count was 3.81 with a standard deviation of 0.915. This resulted in a UCL of 6.561 and an LCL of 1.061. The system is stable, but, since the dirt-count specification for Kieffer White River pulp is only 0 to 15 ppm, the variation in the measurement system alone consumes 36.4% of the specification.

The results using the ScanJet IIc system at 300-dpi resolution are displayed in **Fig. 2**. The reduction in variation is readily apparent, with the standard deviation reduced to 0.312 using the ScanJet IIc system. However, two averages obtained during the study were out of statistical control (i.e., they exceeded the up-

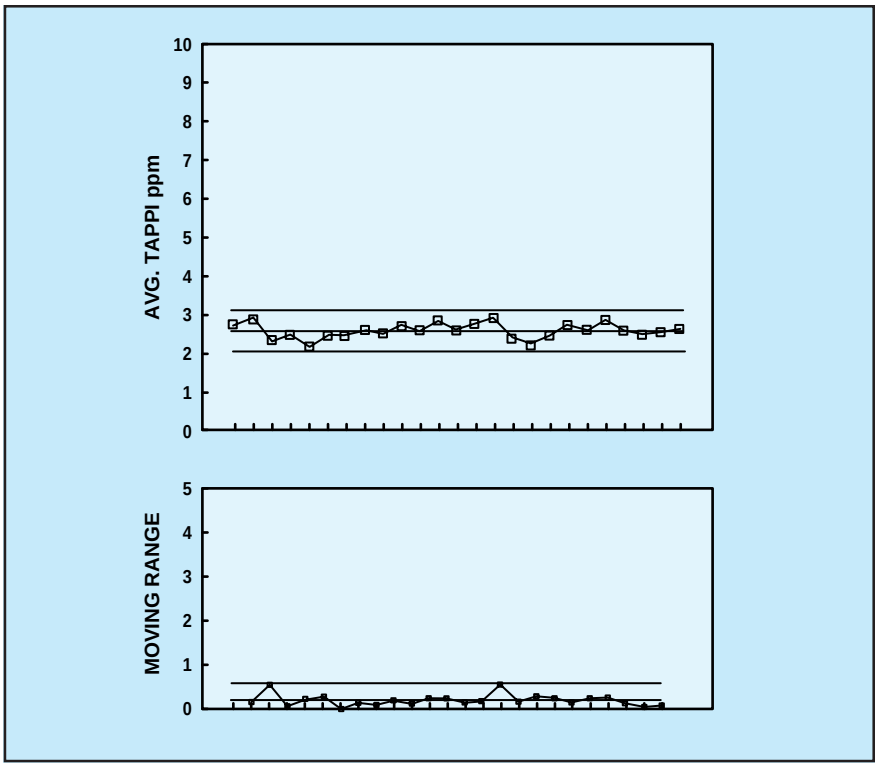
per control limit), something not observed with the ScanJet Plus. The special causes of variation that produced these readings were not identified; however, they were excluded from the analysis of the system variation. With the lower standard deviation, this measurement system consumes only 12.5% of the specification spread, a significant reduction from the results of the ScanJet Plus system.

Figure 3 shows the results from the ScanJet IIc system at 400-dpi resolution. The variation is again reduced, this time to a standard deviation of only 0.174. Using this configuration, the measurement system variation consumes only 7.0% of the specification spread, and no out-of-control points (i.e., special causes of variation) were observed during the study.

Table II compares the results outlined above and shows the calculated F statistic. The UCL for the calculated F value (i.e., the value of F exceeded 5% of the time for samples of this size when the populations have the same variance) is only 1.93 *(5)*. This means that for two measurement systems to be statistically different, the calculated F value must exceed the UCL, which is the case for the ScanJet IIc at both resolutions (22.03 at 300 dpi, 41.83 at 400 dpi) when compared with the ScanJet Plus system.

Finally, an examination of accuracy was attempted using the particle-size range of 0.07 to 0.04 mm^2 from the TAPPI Dirt Estimation Card. Assuming that the sizes of the particles reported on the card are accurate, their presence would produce a 437.2 ppm dirt count in the area over which the scanner analyzed. While this analysis does provide some information, in recycling operations the ink particles are not always the perfect black on a white background as provided on the TAPPI Card. Therefore, it is important to define a detection setting that measures particles of varying colors and shades of gray rather than strictly black particles.

3. Control chart for Optomax speck check using HP ScanJet IIc (400-dpi resolution)



While no system exactly measured the 437.2 ppm target provided by the TAPPI Card, the ScanJet IIc scanner provided the highest accuracy with a bias of 16.03 at 300 dpi and 20.67 at 400 dpi. Also, as seen earlier in the variation analysis, the variation between readings is significantly reduced with the Optomax using the ScanJet IIc scanner. The ScanJet IIc at 400 dpi had a standard deviation of 1.61, an improvement of over 96% versus the Optomax using the ScanJet Plus scanner.

Conclusions and recommendations

The procedure used here to evaluate the Optomax Speck Check System in various configurations can be used to quantify the relative accuracy and precision of two "dirt count" methods versus each other and versus results obtained using the TAPPI test method.

The Optomax system provided dirt-count analyses with far less variation when configured with the HP ScanJet IIc scanner set at 400-dpi resolution than with the same scanner set at 300-dpi resolution or with the ScanJet Plus scanner set at its maximum resolution of 300 dpi. For applications producing pulp and paper with relatively low dirt counts (100 ppm or less), the use of the higher-resolution instrument is strongly indicated to reduce the error in the determination caused by measurement system variation. TJ

Literature cited

1. Clites, S. M., *Tappi J.* 75(11): 79(1992).
2. Koncel, J. A., *Amer. Papermaker* 56(1): 25(1993).
3. *Dirt in Pulp*, TAPPI Test Methods, TAPPI PRESS, Atlanta, 1992, p. 152.
4. *Statistical Methods for Improving Measurement Systems*, QualPro, Knoxville, TN, 1992, p. 39.
5. *Statistical Methods for Improving Measurement Systems*, QualPro, Knoxville, TN, 1992, p. 140.

Received for review Jan. 25, 1994.

Accepted June 16, 1995.