COMPETITIVE ANALYSIS OF NORTH AMERICAN NEWSPRINT PRODUCERS USING COMPOSITE STATISTICAL INDICATORS OF PRODUCT AND PROCESS PERFORMANCE

Patrick Tessier
ISAC Technology Inc., 5962 Signal Ridge Heights SW, Calgary, AB, Canada T3H 2N8

Gordon Broderick
Noranda Technology Centre, 240 Hymus Blvd., Pointe Claire, PQ, Canada H9R 1G5

Philip Plouffe
Papier Masson Ltd., P.O. Box 2400, Buckingham, PQ, Canada J8L 2X3

ABSTRACT

Newsprint samples were collected from 30 different North American mills. Product quality for these samples was described in terms of 25 sheet optical and physical properties, including opacity, machine- and cross-direction tear, static and dynamic friction coefficients, and ash content. Samples were also repulped, and the different furnishes were analyzed in terms of 27 fiber characteristics using the Optest Fiber Quality Analyzer (FQA). Principal-component analysis (PCA) was used to collapse these sheet- and fiber-quality variables into four common trends in newsprint quality, which provide the best resolution in distinguishing among different mills and the pulping processes used. These four composite indicators represent roughly two-thirds of the differences in newsprint quality among the different mills. The remaining variation is attributed to test error and variations in individual sheet properties where these are altered almost independently of one another through the addition of retention aids, color, and/or fillers.

INTRODUCTION

In a consumer-driven newsprint market, being able to compare one's product with competitors' products is of main importance. It provides a marketing tool for establishing one's capability to meet customer requirements. It also gives the possibility to better tailor and control grades and demonstrates the presence of a solid quality-assurance program.

MILL DATA

A total of 46 newsprint samples were collected from 30 mills in Canada and the United States. Pulping processes included thermomechanical pulping (TMP), deinked pulp (DIP), groundwood pulp (GW), high-yield sulfite pulp (HYS), kraft, sulfite, and mixtures of these, as seen in **Table I**.

Mill No.	Pulping process	Newsprint sample number	Mill No.	Pulping process	Newsprint sample number
1	TMP	1	16	DIP	17
2	TMP	2	17	TMP, DIP	18
3	GW, TMP, DIP	3, 34	18	GW, TMP, DIP, Kraft	19
4	TMP, DIP	4	19	GW, TMP, Sulfite	20
5	TMP, DIP	5	20	TMP, DIP, Kraft	21
6	TMP	6, 10, 23, 38	21	TMP	22
7	TMP, DIP	7, 28, 35	22	GW, Sulfite, DIP	25
8	GW, TMP, HYS, DIP	8, 36	23	GW, TMP, Kraft	26
9	TMP, DIP	9, 24, 30	24	TMP, DIP, Kraft	31, 39
10	DIP	11, 29	25	GW, TMP, DIP, Kraft	32
11	TMP, DIP	12	26	TMP, DIP	33
12	TMP, DIP	13, 37	27	TMP, DIP	40
13	TMP, DIP	14	28	TMP, DIP, Kraft	41
14	GW, TMP, DIP, Kraft	15	29	GW, Sulfite	42
15	TMP	16, 27	30	GW, HYS, DIP, Kraft	43, 44, 45, 46

Table I. Pulping processes in 30 newsprint mills and associated sample numbers.

Pulp properties and paper quality were quantified in terms of fiber characteristics and newsprint optical and physical properties. The fiber characteristics (mean length, curl, kinks, and fiber fractions) are listed in **Table II**, and the newsprint optical and physical properties are listed in **Table III**.

Fiber characteristics	Abbreviation in Figs. 1–4	Mean	Minimum	Maximum	COV[†]
Length-weighted fines, %	LWFines	15.92	10.605	26.895	23.80
Mean arithmetic length, mm	MALength	0.4257	0.3065	0.553	13.64
Mean length-weighted length, mm	MLLength	1.343	1.031	1.588	9.14
Mean weight-weighted length, mm	MWLength	2.270	2.0155	2.9915	9.89
Mean arithmetic curl	MACurl	0.04690	0.027	0.0835	30.26
Mean length-weighted curl	MLCurl	0.04915	0.027	0.1005	35.48
Kink index	Kink Index	0.7071	0.33	1.345	31.64
FQA fiber fractions, mm					
0–0.2	0–0.2mm	0.5887	0.5095	0.74875	8.85
0.2–0.4	0.2–0.4mm	0.1393	0.10475	0.17775	12.11
0.4–0.6	0.4–0.6mm	0.0756	0.04	0.109	16.29
0.6–0.8	0.6–0.8mm	0.04693	0.02375	0.0685	21.02
0.8–1.0	0.8–1.0mm	0.03176	0.01075	0.0445	22.08
1.0–1.2	1.0–1.2mm	0.02209	0.00975	0.031	25.38
1.2–1.4	1.2–1.4mm	0.01755	0.00825	0.0285	27.71
1.4–1.6	1.4–1.6mm	0.01376	0.00525	0.022	32.23
1.6–1.8	1.6–1.8mm	0.01187	0.00525	0.02325	35.19
1.8–2.0	1.8–2.0mm	0.008934	0.00345	0.01575	37.00
2.0–2.2	2.0–2.2mm	0.008511	0.0035	0.0145	34.73
2.2–2.4	2.2–2.4mm	0.007228	0.00275	0.01725	43.58
2.4–2.6	2.4–2.6mm	0.005842	0.00225	0.01075	38.75
2.6–2.8	2.6–2.8mm	0.005315	0.00275	0.00875	32.03
2.8–3.0	2.8–3.0mm	0.004049	0.002	0.00775	34.77
3.0–3.2	3.0–3.2mm	0.003576	0.001	0.0075	39.04
3.2–3.4	3.2–3.4mm	0.002543	0.00075	0.00475	37.20
3.4–3.6	3.4–3.6mm	0.001891	0.0005	0.00325	31.73
3.6–3.8	3.6–3.8mm	0.001272	0	0.0025	49.00
3.8–10.0	3.8–10mm	0.002625	0.0005	0.00725	61.71

[†] Coefficient of variation = 100 × (std. dev./mean)

Table II. Fiber characteristics (as measured by Optest Fiber Quality Analyzer).

Newsprint property	Abbreviations in Figs. 1–4	Mean	Mini-mum	Maxi-mum	COV [†]
Opacity	Opacity	94.47	92.24	96.36	0.9395
Brightness	Brightness	58.39	55.35	62.38	2.020
MD tear	MD Tear	228.8	159	289	14.00
CD tear	CD Tear	349.1	260	480	14.64
MD breaking length	MD Break Len	2.465	1.98	3.14	11.86
CD breaking length	CD Break Len	0.7563	0.45	0.93	16.41
Top Parker print surface	Top PPS	3.713	2.82	4.7	12.78
Bottom Parker print surface	Bottom PPS	3.632	3.11	4.9	12.50
Caliper	Caliper	75.78	63.3	93.5	7.652
MD TEA	MD TEA	16.92	9.46	33.29	28.53
CD TEA	CD TEA	13.48	6.97	21.36	24.88
Burst	Burst	62.83	43	91	18.82
MD elongation	MD Stretch	1.171	0.82	1.75	17.15
CD elongation	CD Stretch	2.509	1.84	4.56	19.39
Formation	Formation	9.96	5	19.5	30.39
Basis weight	Bas Weight	48.73	46.24	49.72	1.439
Ash	Ash	1.952	0.26	7.16	85.23
Static friction	Static Frict	0.3135	0.2	0.68	24.71
Dynamic friction	Dyn. Frict	0.2604	0.17	0.45	19.31
Scattering coefficient	Scattering	51.44	44.88	59.06	7.134
Absorption	Absorption	5.832	4.43	6.81	8.422
L^*	L	83.12	81.87	86.01	0.8150
a^*	a	–0.1902	–1.43	0.78	271.3
b^*	b	4.595	3.67	5.92	9.421
Bulk	Bulk	1.555	1.309	1.906	7.228

[†] Coefficient of variation = 100 × (std. dev./mean)

Table III. Newsprint properties from laboratory tests.

ANALYSIS OF FIBER CHARACTERISTICS AND NEWSPRINT QUALITY

Principal-component analysis (PCA) was used to project the 27 fiber characteristics measured by the Optest Fiber Quality Analyzer (FQA) and the 25 newsprint properties onto a number of fundamental properties or indicators (common factors) that provided the best resolution in distinguishing product properties among competing mills.

Principal-component analysis is a standard multivariate statistical method and is well suited for analyzing large sets of correlated data. PCA is used to project the original variables onto a lower-dimensional score space by an orthogonal decomposition, thus facilitating analysis of the original data. The principal components are the projections of the original variables along directions, which are given by the eigenvectors of the covariance matrix of the original data. The information contained in the original data is thus retained. Once the PCA model is formed, new data can be seen as projections onto single eigenvectors or onto a plane formed by a pair of eigenvectors. The nonlinear iterative partial least squares (NIPALS) algorithm developed by Wold *(1)* was used to perform the PCA calculations in this study. An overview of NIPALS and other algorithms is available in recent work by Jackson *(2)* and Broderick *(3)*.

Four fundamental properties, each represented by a principal component, were identified when analyzing the data. These four principal components, or indicators, explain roughly 60% of the differences in newsprint quality among the 30 competing mills. The remainder of the variation is partly attributed to test random error and is associated with changes in quality whereby each property changes almost independently of the others. This additional freedom between properties is indicative of the type of changes that can be applied to the product at the paper machine, such as the addition of retention aids, color, and fillers. For instance, fillers increase sheet opacity without significantly affecting strength so long as the dosage remains below a certain threshold concentration. Above this concentration, the inert particles will begin to interfere with interfiber bonding and reduce tensile strength.

PHYSICAL INTERPRETATION OF THE COMMON INDICATORS

The loadings associated with each of the four distinct common indicators, or principal components, can be used to find a physical interpretation of these fundamental properties represented by the four most significant eigenvalues of the PCA model.

The variable loadings presented in **Figure 1** describe a phenomenon by which TEA, burst, stretch, and breaking length increase at the expense of tear. This can be related to fiber development and available area for bonding. The addition of mechanical pulp will introduce organic fine material potentially helpful in cementing fiber–fiber bonds. However, mechanical pulp fibers are also much stiffer, have more kinks, and will penalize web consolidation and bonding. The addition of long stiff mechanical pulp fibers will increase tear strength but decrease tensile properties. Flexible fibers measuring 0.6–3.4 mm are associated with a positive loading in PC No. 1 and, hence, contribute to an increase TEA, burst, and breaking length.

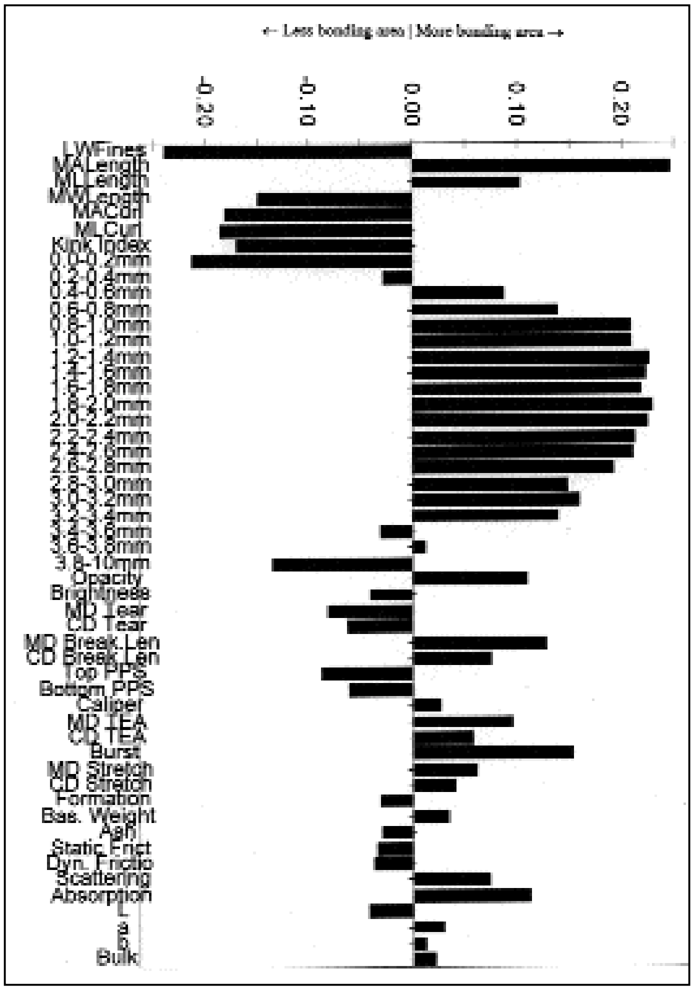

Figure 1. Loading of fiber properties and newsprint quality on principal component No. 1 (bonding area).

The loadings in **Figure 2** show the effect of the long-fiber content on newsprint properties. The long fibers (>2.5 mm) generally come from the addition of softwood kraft pulp. They will improve tear but can also lead to rougher sheet surfaces, as shown by the Parker print-surface values as well as increased bulk and caliper. Average fiber length, curl, and kink index also increase with the addition of softwood kraft pulp.

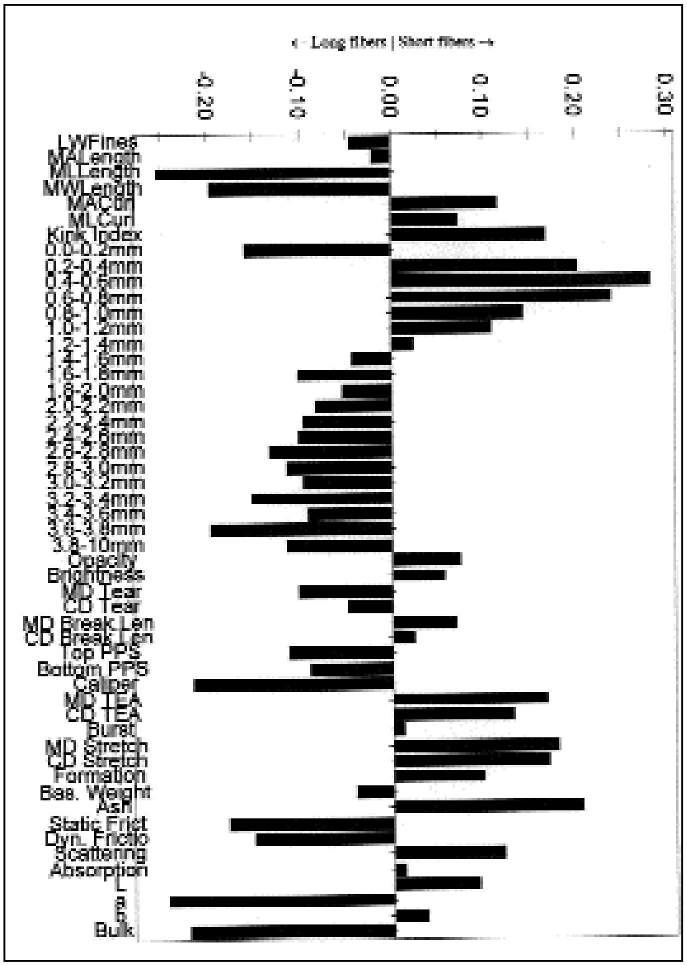

Figure 2. Loading of fiber properties and newsprint quality on principal component No. 2 (fiber length)

Results in **Figure 3** show a loading pattern that is less sensitive to fiber length, with the exception of the 0.2–0.4-mm fraction. Tear, burst, stretch, and tensile strength increase together as caliper and bulk are reduced. This type of response can be attributed to an increase in sheet consolidation achieved by a combination of higher wet pressing and reduced calendering. Increasing wet pressing will improve wet web strength and tensile while lowering bulk, caliper, and porosity. Increasing calendering will improve smoothness but will lower tensile, tear, burst, and MD stretch.

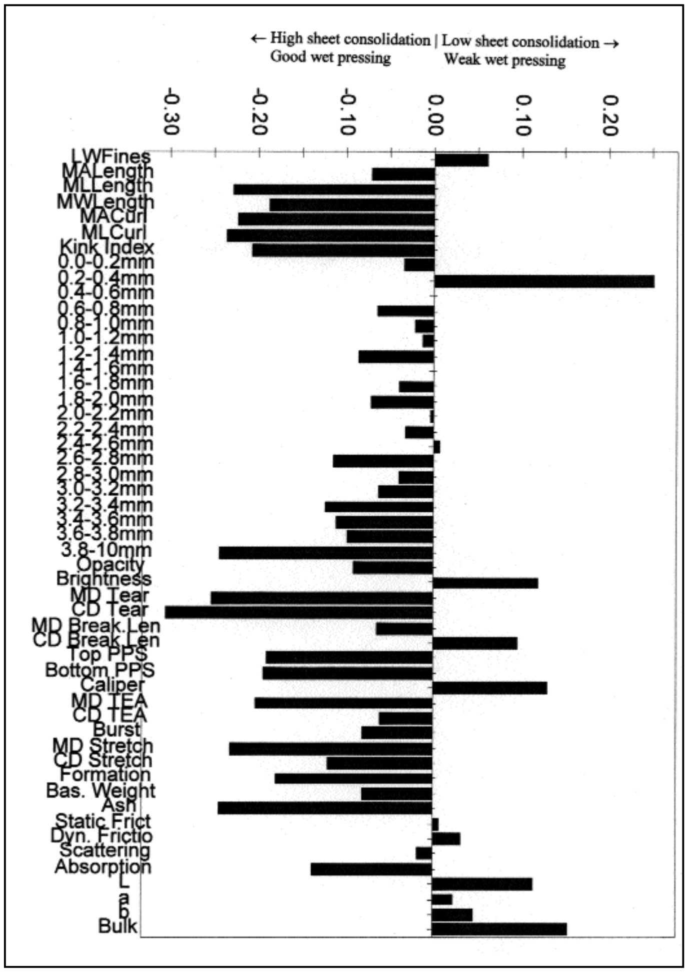

Figure 3. Loading of fiber properties and newsprint quality on principal component No. 3 (sheet consolidation).

The loading of the variables presented in **Figure 4** describes a change by which brightness is increased at the expense of opacity. Here again, the contribution of the fiber length fractions is minimal, with the exception of some of the finer fractions, pointing to a chemical phenomenon rather than a physical change to the sheet. This behavior probably results from the addition of kraft fibers that are brighter but that would lead to lower sheet light absorption, thus lower opacity. This would also increase tear, as shown in Figure 4. The addition of mechanical pulp, on the contrary, increases the sheet light absorption but lowers brightness.

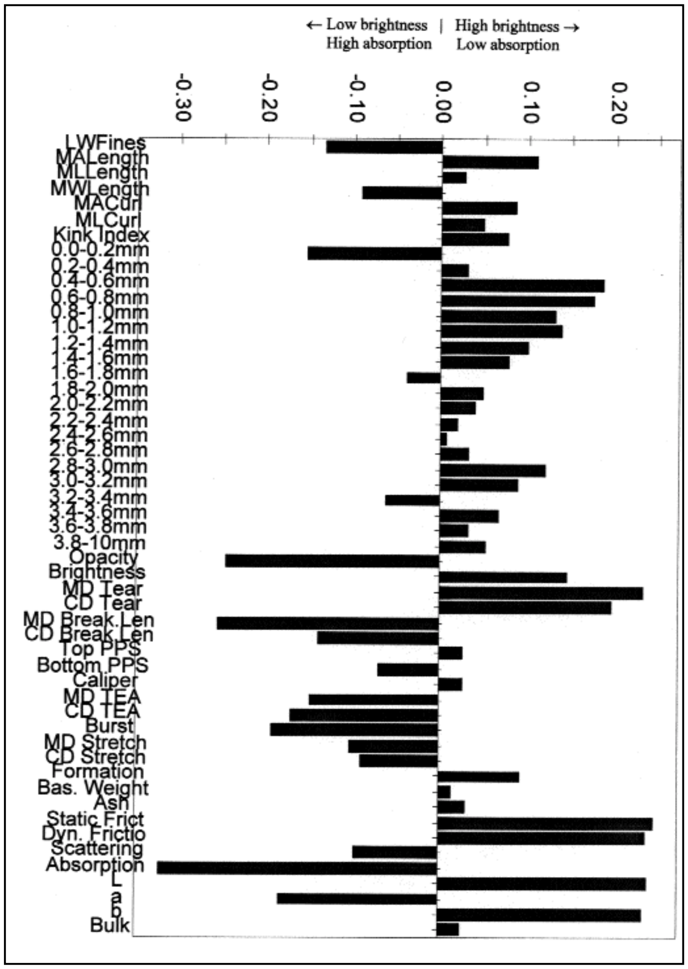

Figure 4. Loading of fiber properties and newsprint quality on principal component No. 4 (sheet brightness).

In summary, the four key phenomena identified by principal-component analysis are:

1. Changes in tensile strength that can be linked to increased flexibility in medium and long fibers (0.6–3.4 mm) and to surface development. Surface development has been identified as the most important phenomenon, as it is associated with the largest eigenvalue when performing the orthogonal decomposition.
2. Changes in surface roughness and tear strength that are consistent with the addition of long coarse fibers and increased network continuity. This is the second most important phenomenon.
3. Changes in sheet strength and surface smoothness that are consistent with changes in sheet consolidation through wet pressing and/or calendering.
4. Changes in sheet light absorption, which would be brought about by the addition of bright kraft fibers (higher brightness and lower opacity) or the addition of mechanical fibers or clay or fillers (lower brightness and higher opacity).

The first two phenomena — surface development and long-fiber content — are consistent with the L and S factors introduced by Forgacs *(4)*. These principal components can now be used as a new set of coordinates to plot the 25 optical and physical properties used to describe newsprint quality and illustrate the relationships among these properties, as shown in **Figure 5**. For instance, increasing fiber bonding (principal component No. 1) and decreasing the long-fiber content (principal component No. 2) will produce newsprint with higher tensile, breaking length, stretch, burst, and scattering coefficient. The opposite will result in higher tear, caliper, and bulk. The interrelations between properties, which lead to other latent properties, can be seen in the same way by projection onto the other principal components. This is a very efficient way to determine how the process operating conditions (refining, calendering, etc.) and the ratios of pulp in the blend (DIP, kraft, etc.) can be altered to meet customers specifications.

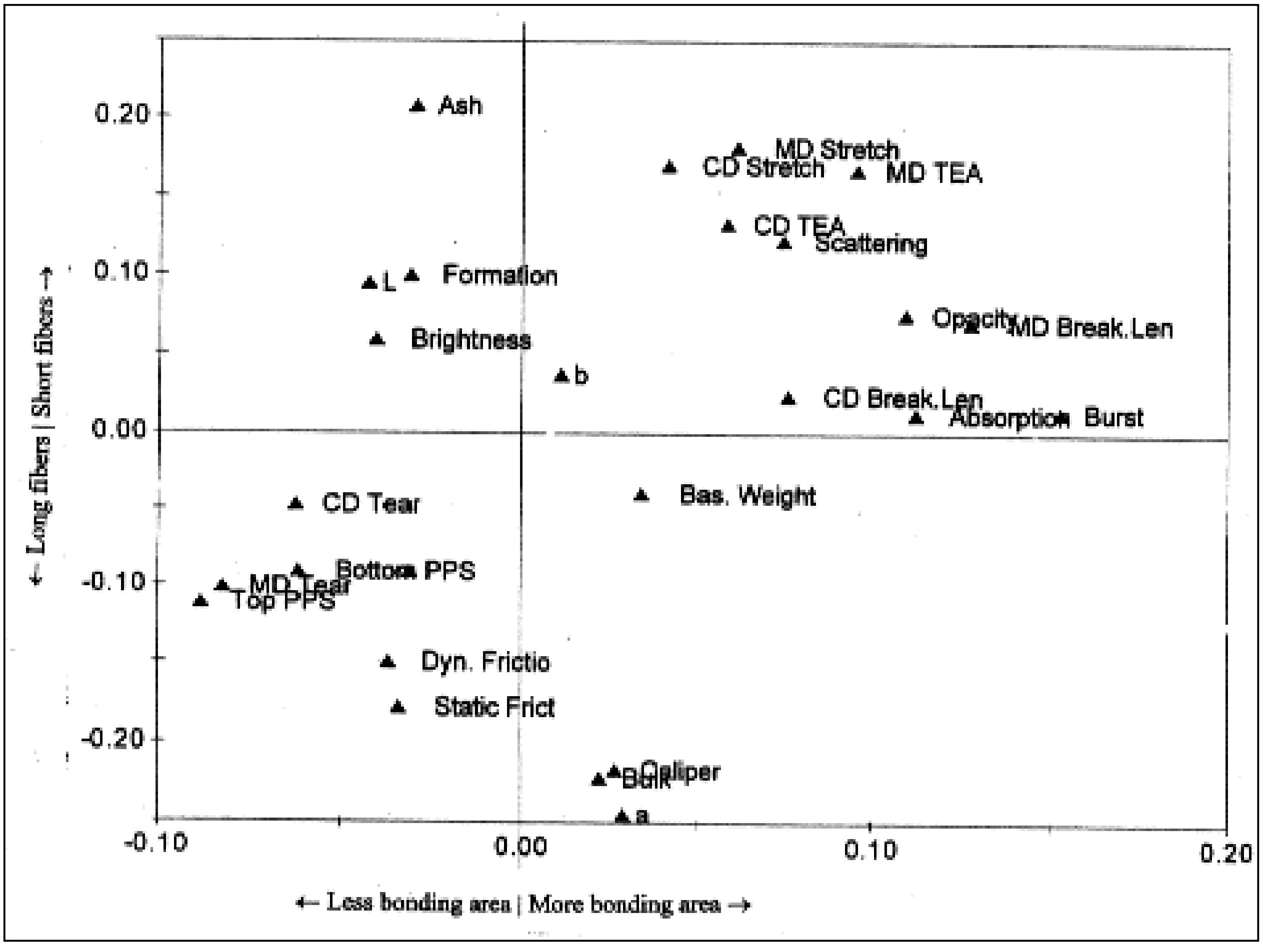

Figure 5. Projection of newsprint optical and physical properties onto surface development (x-axis) and fiber length (y-axis).

IMPACT OF PULPING PROCESSES ON NEWSPRINT QUALITY

In much the same way, compressing the data into a more manageable coordinate space, principal-component analysis also makes it possible to compare various newsprint products and the processes with which they were produced. This can now be achieved using the four composite quality factors we have identified instead of the original 25 sheet properties measured. Producers who share similar coordinates (scores), or who are close to each other, in the PCA space have similar fiber development, long-fiber content, and sheet properties.

Figure 6 shows the positions of the 46 newsprint samples, referred to by their numbers in Table I, when the two most important composite indicators (fiber bonding and long-fiber content) are used as *x*- and *y*-axes, respectively.

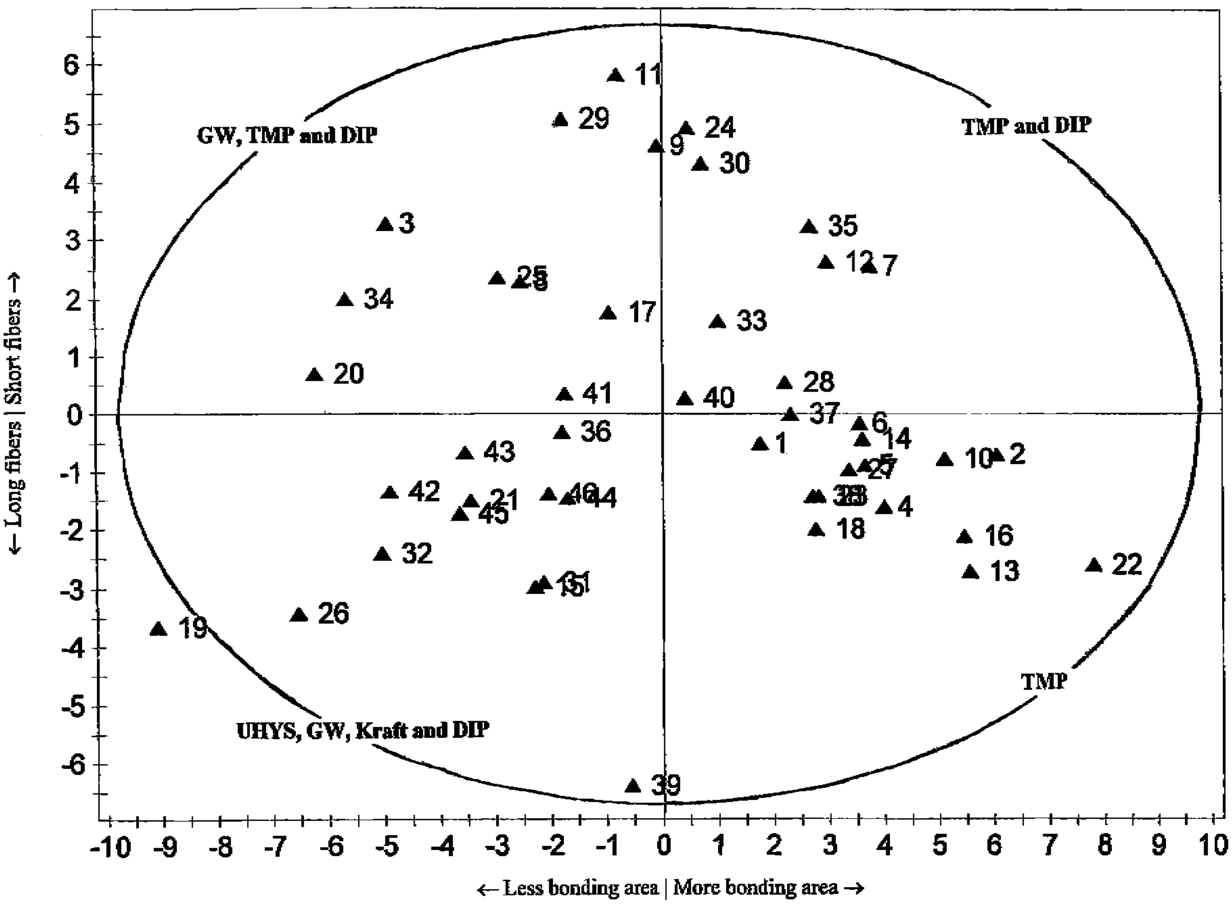

Figure 6. Projection of newsprint samples onto surface development (x-axis) and fiber length (y-axis).

When plotted in PC-space, newsprint samples produced in TMP mills fall into the lower right quadrant, indicating that the TMP process leads to better surface development/bonding and longer fiber content.

Newsprint samples from blends of TMP and deinked pulp can be found in the upper right quadrant. Furnishes produced from blends of TMP and DIP are also well developed but have shorter fibers than pure TMP pulp.

The upper left quadrant mostly includes newsprint samples made from a mixture of groundwood, sulfite, TMP, and DIP pulps. The fibers in the combined furnish are shorter because of the presence of groundwood and DIP pulp in the blend, and the overall fiber development is less than for TMP pulp.

Finally, the lower left quadrant is home to newsprint produced from mixtures of groundwood, DIP, kraft, and ultrahigh-yield sulfite (UHYS) pulps. The main difference between the upper left and lower left quadrants results from the addition of kraft pulp. Newsprint furnishes containing kraft have a higher long-fiber content, but the surface development is lower than for TMP pulps.

MAKING USE OF THE LOADING AND SCORE PLOTS

It should be clear by now that the four composite indicators provide an efficient and easy way to differentiate between pulping processes and newsprint quality by defining a system of new coordinates. This method conserves the richness of information but enables visualization in a lower dimensional space. Competing mills with the same pulping process can use this information to adjust their existing process operating conditions to meet customers demands and to compare themselves with one another in overall quality. For instance, TMP Mill 15, from which newsprint sample Nos. 16 and 27 were obtained, can produce the same kind of newsprint as TMP Mill 21 (newsprint sample No. 22) if it can slightly increase fiber development.

As another example, to approximate a typical TMP-based sheet, a newsprint producer using a CMP–groundwood mix would have to increase component No. 1, i.e., increase bonding surface through better refining and fines retention. Increasing the second indicator requires addition of long coarse fiber. Finally, applying better wet pressing will in turn lower the value of the third composite indicator. These conclusions are easily and rapidly observed using the simple graphical representations offered by principal-component analysis.

However, there may be limitations. A newsprint mill using a mixture of groundwood, UHYS, and kraft pulp cannot perfectly match newsprint from a mill using TMP and DIP. One has to understand the advantages and disadvantages of existing pulping processes and approach customers who might be interested by the resulting range of products. Some mills may have two or more paper machines that can be dedicated to either offset or letterpress newsprint. It may be an advantage to favor strength or smoothness, depending on the customer's printing press. The ability to graphically represent your product's position vs. the competition while knowing your product's strengths and weaknesses provides a significant business advantage. For instance, Mill 19 has the highest tear, while newsprint from Mill 3 has the best formation. Mill 24 provides high tear, bulk, and caliper.

The score plot can also be used to assess product quality variability. Mill 9 (TMP+DIP), from which we got sample Nos. 9, 24, and 30, makes very consistent newsprint, since the three samples are very close to each other on the score plot. In contrast, Mill 7 (sample Nos. 7, 28, and 35) and Mill 30 (sample Nos. 43, 44, 45, and 46) were not as successful at reducing product quality variability. In one case, the variability was related to seasonal changes in the chip size distribution. This problem could be corrected by implementing a quality control program in collaboration with the mill wood chip suppliers.

CONCLUSION

Principal-component analysis (PCA) was used to collapse 27 fiber characteristics and 25 newsprint properties into four fundamental properties that provided the best resolution in distinguishing among 46 newsprint samples collected from 30 North American mills.

The first two fundamental properties — fiber bonding and fiber length — explain close to 50% of the similarities or differences among the pulp samples.

The loadings resulting from the PCA analysis were used to map the 25 newsprint properties in relation to these two fundamental properties, making it easier to understand how fiber bonding and fiber length affect each newsprint property and how these properties interact.

Finally, the score plots for the first two fundamental properties were used to differentiate among pulping processes. TMP mills produce pulp fibers that are longer and have better bonding property. Pulp blends from groundwood pulp, deinked pulp, and TMP have shorter fibers and lower bonding property.

The information contained on the loading plots and score plots can be used to target customers more efficiently or to modify existing process operating conditions.

LITERATURE CITED

1. Wold, S., "Nonlinear estimation by iterative least squares procedures," in *Research Papers in Statistics* (F. N. David, Ed.), Wiley, New York, 1966.
2. Jackson, J. E., *A User's Guide to Principal Components*, Wiley, New York, 1991.
3. Broderick, G., Paris, J., and Valade, J. L., "A composite representation of pulp quality," *Chemometrics and Intelligent Laboratory Systems* 29(1): 19(1996).
4. Forgacs, O. L., "The characterisation of mechanical pulps," *Pulp Paper Mag. Can.* 64(Convention issue): T89(1963).

Received: February 3, 2000
Accepted: October 15, 2000

This paper was accepted for abstracting and publication in the March 2001 issue of *TAPPI JOURNAL*.

TAPPI Website: www.tappi.org