USING ROLL HARDNESS TO SCREEN FOR EXCESSIVE WEB BAGGINESS

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ABSTRACT

Various methods are available for quantifying bagginess. But they can be tedious and impractical in a production setting. Often one just needs to know if a roll is too baggy to run without wrinkling during converting. Screening rolls offline can save time and reduce scrap when the alternative is loading the roll and making machine adjustments on the fly to eliminate wrinkles from baggy edges.

In this paper a method for correlating average roll hardness and cross direction hardness profile to runnability using intraclass correlation and binary logistic regression tools is described. Here runnability means running near target line speed without wrinkling. The outcome is the probability that a particular roll will exhibit enough bagginess to impact runnability. Then the decision to reject the roll without running can be made depending on how much risk is acceptable. This information can then be relayed to the web supplier to help reduce bagginess at its source.

NOMENCLATURE

CD	Cross direction
L_i	Cross direction position, Lane i
P(acceptable)	Probability that a roll is acceptable

INTRODUCTION

Baggy web is a fact of life and having a robust process means being able to run mildly baggy web without creating defects downstream. Baggy edges will create wrinkles in a laminating nip if the bagginess can't be pulled out by increasing web tension.

It is difficult to know before a roll is mounted and run through the process if the bagginess is enough to create problems. The "try it and see" method wastes time and creates scrap which must be edited out. If the roll is so baggy that it can't be used at all, the raw material must be returned to the supplier. If enough replacement material is not on hand, orders will be late.

This paper looks at bagginess from a converter's perspective. The converter has no control over the manufacture of the material, but has purchased it from a supplier. So the options available to the converter for dealing with baggy web are to try to make it work, send it back to the supplier, or eventually find another supplier.

This work grew from a situation where feedback to a supplier had not been enough to prevent continued shipments of baggy material. To save the converter machine time and reduce scrap costs, a method to screen out excessively baggy rolls was developed.

While bagginess is simple to define, it is not a quick or convenient property to measure. Bagginess can be quantified by measuring the difference in length of strips cut from a web or by measuring the curvature of a length of web [1]. While neither of these methods requires sophisticated equipment, they both require time, space, and patience.

Roll hardness, on the other hand, is quick and easy to measure and CD variation in hardness has been shown to correlate with caliper profile [2]. Caliper profile is known to create bagginess in wound rolls when the areas of higher caliper are stretched relative to their lower caliper neighboring lanes [1]. Therefore it's likely that a relationship between roll hardness and bagginess exists.

STRATEGY

To expect a supplier to take back material that hasn't been run requires convincing data linking the hardness measurements to bagginess. To develop the criterion for rejection in this study, 63 rolls of film (0.78m in diameter and 1.5m wide) which exhibited varying degrees of bagginess on one edge were evaluated for their hardness profiles, then for bagginess. The bagginess data was combined with line speed to determine runnability. Then a correlation between the hardness and runnability was sought.

HARDNESS MEASUREMENT

To compare the measurement error to the variation in hardness across a roll, three hardness measurements within a lane at five lanes across the roll were taken as in Figure 2. This sampling plan gave a typical hardness profile as shown in Figure 3. The width of the control limits in the x-bar chart in Figure 3 represents the test variation. The x-bar chart also shows that the variation in hardness across the roll is much greater than the test variation. For each roll tested, the CD hardness profile was described by the difference in hardness of the 5 lanes and was called "Range of Lanes" in the analysis that follows. For the roll in Figure 3, the Average Hardness was 513 and the Range of Lanes was 182.

Figure 1 – PAROtester

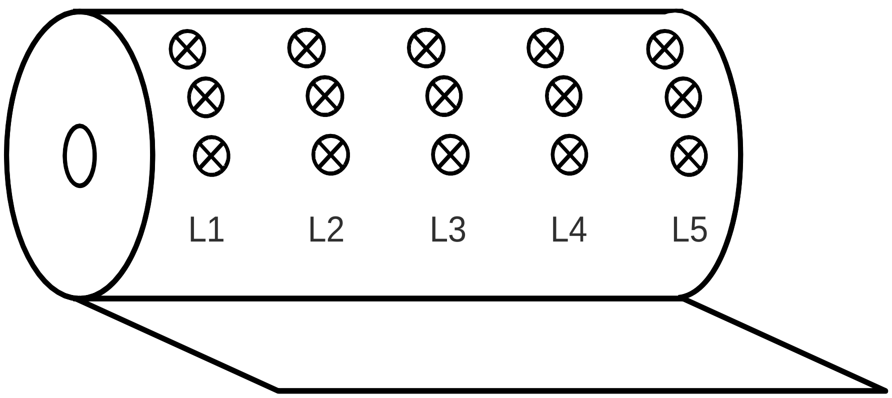


Figure 2 – Hardness Sampling Plan

The gauge study used 3 operators and 5 lanes of 2 rolls (A and B) as 10 parts with 3 measurements per lane as shown in Figure 4. The study results in Figure 5 showed that the PAROtester could discriminate the hardness differences between lanes, showed very little operator bias, and had a measurement error of ±22 hardness units. Although there was good agreement between operators, since 2 of the operators had wild measurements (or points outside the control limit of R-chart in Figure 5), further hardness testing continued with multiple measurements per lane.

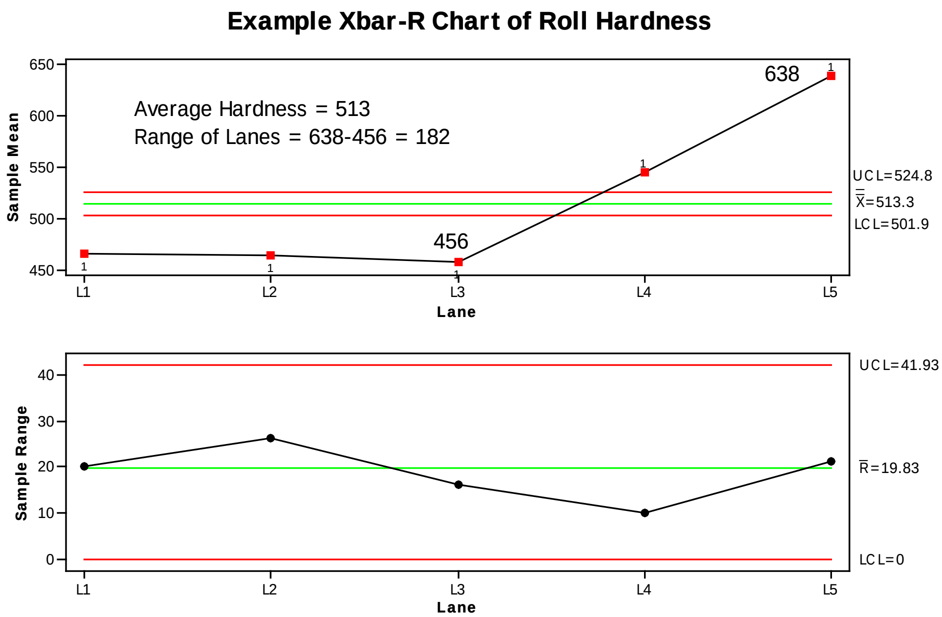


Figure 3 – Example Hardness Profile, Subgroup for lane =3

Roll	Lane	Part
A	1	A1
	2	A2
	3	A3
	4	A4
	5	A5
B	1	B1
	2	B2
	3	B3
	4	B4
	5	B5

Figure 4 – Setup for PAROtester gauge study

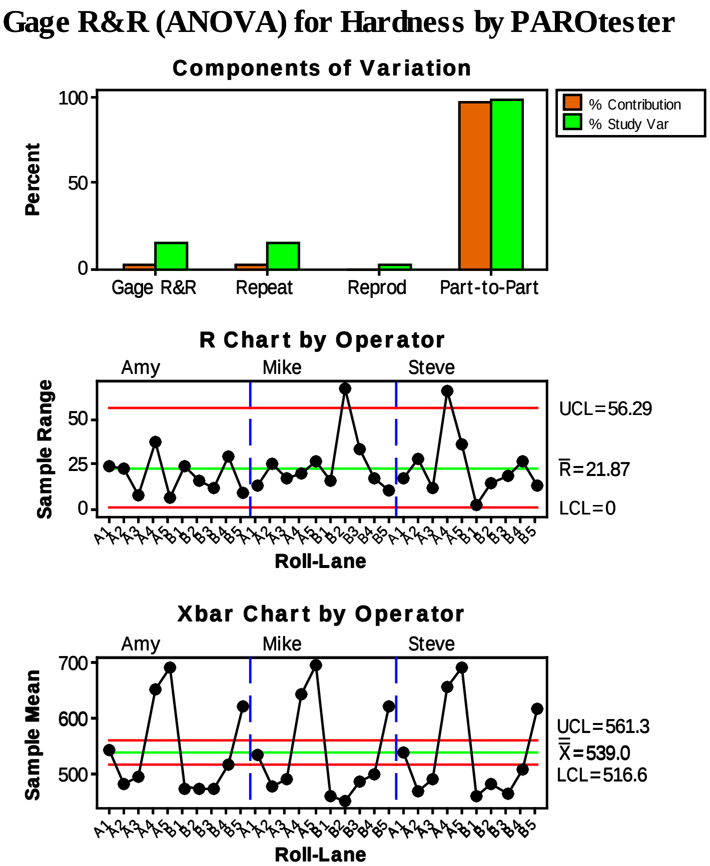


Figure 5 – Gage R&R of Parotester by Minitab Software

BAGGINESS MEASUREMENT

To make the subjective, visual assessment of bagginess of a web running on a laminating line reliable and reproducible, first a rating system was established (Figure 6). Then using this scale, two operators separately rated ten rolls of film during normal production.

Rating	Appearance of Bagginess	
1	None	Yes
2	Slight	Yes
3	Moderate	Probably
4	Severe	Probably not
5	Kick Out	No

Figure 6 – Rating Scale for Bagginess

The bagginess ratings by the operators (Judge 1, Judge 2) were analyzed as an Intraclass Correlation (ICC) which is used to evaluate whether several people using the same subjective rating system are consistent between themselves [4]. A correlation coefficient at least 0.7 or higher indicates an adequate rating system. The ICC in Figure 7 with a coefficient of 0.75 showed that different operators would rate the bagginess of the rolls quite similarly.

Roll	Judge 1	Judge 2		SUM	SUM^2	Sum of squares
1	2	4		6	36	20
2	1	1		2	4	2
3	4	4		8	64	32
4	2	2		4	16	8
5	3	3		6	36	18
6	5	5		10	100	50
7	3	3		6	36	18
8	4	2		6	36	20
9	2	3		5	25	13
10	5	5		10	100	50
SUM	31	32		63	453	231
SUM^2	961	1024		1985		
Sum of all squared ratings:				231		
Average of all ratings:				3.15		
Sum x average:				198.45		
Sums of Squares:			DF	Mean Sq.	Component	
For Raters		0.05	1	0.05	JMS	
For between rolls		28.05	9	3.12	BMS	
For total		32.55	19	1.71		
For within rolls		4.5	10	0.45	WMS	
For error		4.45	9	0.49	EMS	
Situation 1		0.75		Each judge		
Situation 2		0.86		Averaged ratings		

Figure 7 – Intraclass Correlation for Bagginess Ratings

RUNNABILITY

Then 63 rolls were rated as acceptable or unacceptable as in Figure 8 based on the following criteria:

a) Rating of 3 or better

b) Ran at an average speed of at least 70% of target line speed

Roll	Average Hardness	Range of Lanes	Line Speed ≥70% of Target?	Bagginess Rating	Acceptable?
1	519	157	yes	2	1
2	546	193	no	2	0
3	545	189	yes	1	1
4	532	267	yes	5	0
5	570	185	no	4	0
6	517	72	yes	3	1

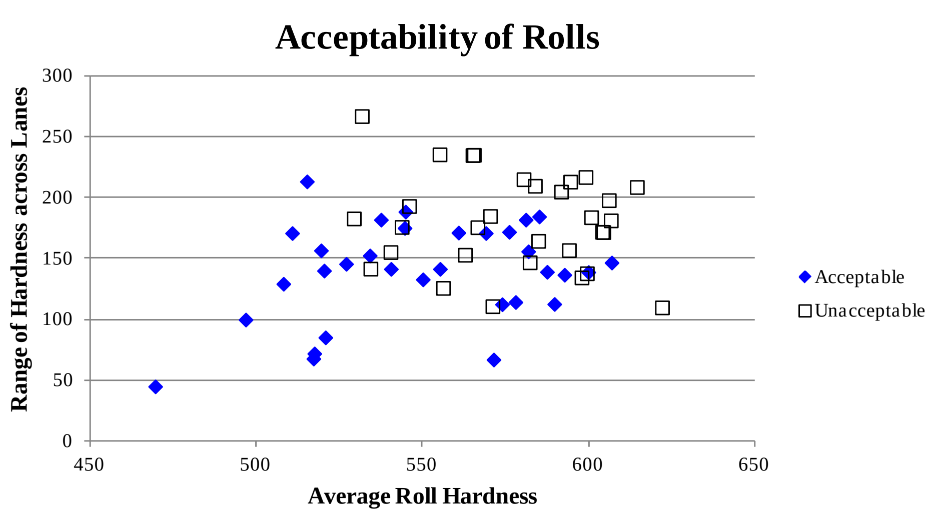
Figure 8 – Examples of Roll Data and Runnability Determination

HARDNESS TO RUNNABILITY CORRELATION

Because one would expect that winding rolls tighter would exaggerate the development of baggy edges if the root cause was an uneven caliper profile, the hardness profile (Range of Lanes) was plotted against the Average Hardness for both acceptable and unacceptable rolls.

Figure 9 shows that the swarm of good rolls is shifted to the lower left corner and the swarm of bad rolls is shifted to the upper right corner. This suggests that a roll wound more tightly (as measured by Average Hardness) is more sensitive to CD variation (as measured by the Range of Lanes).

Because the converter was willing to slow the laminating line down for some rolls to keep production going, the actual quality of all the “acceptable” rolls was not the same; slowing down slightly improved the bagginess rating. This explains in part the overlapping of the good roll space and the bad roll space in Figure 9.



For this study, binary logistic regression was used to evaluate the relationship between the predictor variables and a binary response (Acceptable/Unacceptable) [5]. The predictor variables were Range of Hardness and Average Hardness. The outcome of a binary logistic regression is a model which predicts the probability of a positive response, in this case, an acceptable roll.

Minitab statistical software was used for the analysis shown in Figure 10. Since both their p-values were less than 0.05, both Average Hardness and Range of Lanes were significant predictors of Acceptability. The predictor coefficients for the Logit function in Equation 1 are also shown in Figure 10.

The probability of a roll being acceptable, P(acceptable), as calculated by Equation 2 is shown in the contour plot of Figure 11. The contours show lines of equal probability of runnability or an acceptable degree of bagginess. The upper right corner, where the probability is less than 10%, represents the baggiest rolls – the ones most likely to create wrinkles if run.

Binary Logistic Regression: Acceptability versus Avg Hardness, Range of Lanes

Link Function: Logit

Response Information

Variable	Value	Count
Acceptability	1	33 (Event)
	0	30
Total		63

Logistic Regression Table

					Odds	95% CI	
Predictor	Coef	SE Coef	Z	**P**	Ratio	Lower	Upper
Constant	**21.3998**	6.94766	3.08	0.002			
Avg Hardness	**-0.0285978**	0.0112888	-2.53	**0.011**	0.97	0.95	0.99
Range of Lanes	**-0.0314457**	0 .0099141	-3.17	**0.002**	0.97	0.95	0.99

Log-Likelihood = -31.050

Test that all slopes are zero: G = 25.094, DF = 2, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	53.9686	60	0.695
Deviance	62.0996	60	0.401
Hosmer-Lemeshow	17.1313	8	0.029

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	808	**81.6**	Somers' D	0.64
Discordant	179	**18.1**	Goodman-Kruskal Gamma	0.64
Ties	3	0.3	Kendall's Tau-a	0.32
Total	990	100.0		

Figure 10 – Minitab analysis results for Binary Logistic Regression

$$Logit = 21.4 - 0.028 AvgHardness - 0.031 RangeLanes \qquad \{1\}$$

$$P(acceptable) = \frac{1}{\left(\frac{1}{\exp(Logit)} + 1\right)} \qquad \{2\}$$

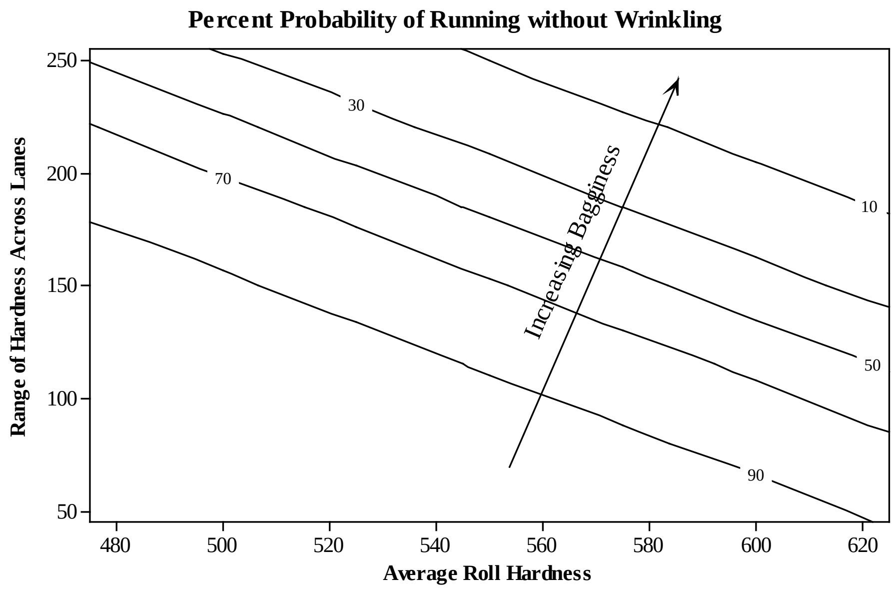


Figure 11 – Contour Plot of Probability of Runnability

1) Have 2 people rate the bagginess of each roll for the initial data set and average the ratings (ICC coefficient improves from 0.75 to 0.86)
2) For the harness testing, omit any wild measurements in the calculation of Average Hardness and Range of Lanes
3) Rate the bagginess of all the rolls at target line speed

SUMMARY

A method was developed for using roll hardness to weed out rolls of film with excessively baggy edges. The result is the probability of a particular roll meeting the criteria of being no more than moderately baggy and being able to run to at least 70% of target line speed.

With the final contour plot, the converter and supplier can negotiate which countour line represents an appropriate point for rejection balancing the risks to both. Then an operator could test the hardness profile of a roll, see where it falls on the contour plot, and whether it falls in the rejection zone or not. Applying this technique could save the converter significant downtime and scrap while the supplier works on improving product quality.

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