“I Am in Spec . . . but Where Did my Softness Go?”

Solving Tissue Softness Problems with Data Analytics

New developments with Data Analytics, as well as softness measuring and testing techniques, now allow tissue makers to use the Geometric-Mean Breaking-Length (GMBL) as an important tool to reduce softness variations. This gives them the ability to systematically reduce basis weight in the sheet which, in turn, can achieve significant cost savings for fibers, energy, and chemicals, while at the same time, potentially allowing machine speed to increase.

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ABSTRACT

A perfect storm is a rare combination of events that drastically aggravates a situation.

This paper shows how it is possible to have Machine Direction Tensile (MDT), Cross Direction Tensile (CDT) and Basis Weight (BW) all within specifications and yet the resulting Softness is unacceptable. To attempt to understand and solve this, we will begin by defining the **Geometric-Mean Breaking-Length (GMBL)** and demonstrating how this compound variable influences softness and magnifies softness variation. Several simulations are provided to demonstrate these points. Traditional methods to control softness are discussed and shown to be lacking in precision and accuracy. Only the newly-developed TSA instrument from Emtec shows promise as an excellent method to accurately and consistently measure total softness[1]. However, the instrument needs to be calibrated with a professional panel. The body of information regarding these aspects of softness is then summarized, leading to several important conclusions. The recommendations provide several ways to reduce softness variation, while also offering a strategy for substantial cost savings.

INTRODUCTION

Customers that buy premium bath and facial tissue rate softness as the number one attribute influencing their buying decision. Companies that produce high softness products enjoy higher margins and profits. However, delivering consistent softness is also crucial because consistent properties build brand loyalty and market share which, in turn, reduces advertising and promotional costs. Unfortunately, many companies achieve high softness but fail to control variation. This leads to higher costs, rejects, and sub-par product entering the market. Ultimately, sales growth and branding suffer. In this paper, I discuss one very pragmatic and low-cost way to reduce softness variation, lower your costs and potentially increase softness. To proceed, we need to explore what drives softness and why it varies . . . Even though all other product measures are within specification.

MAIN DRIVER OF SOFTNESS

Softness is a subjective measure, which means that each person may have a different perception of the softness level (Ref-5). Softness is also multi-dimensional. Some researchers have identified up to nine various components of softness. However, the three key attributes of softness are:

- Smoothness;
- Flexibility; and,
- Bulk(cc/g). [2]

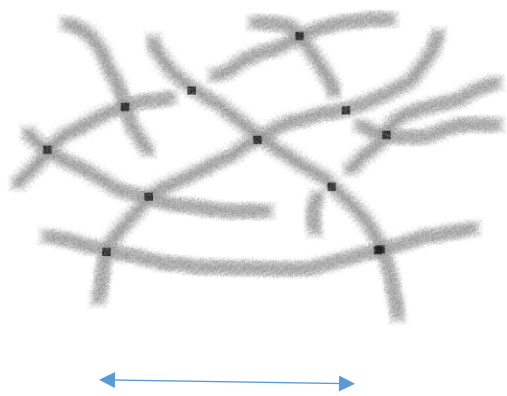
Unfortunately, we do not have a softness knob on the tissue machine that we can turn to simply control softness! However, we know that strength is a primary property affecting softness through its influence on flexibility and bulk. For example, Figure 1 shows a collection of fibers bonded together. The dewatering process presses fibers together – creating more inter-fiber bonds which, in turn, creates more strength. The higher strength that results means creping forces are less capable of disrupting the web to create a thicker, bulkier sheet. Also, more bonds reduce the length between bonds (mean free fiber length) shown by the double arrow in Figure 1. The reduced

[1] The best TSA results are achieved when calibrated using a professional panel with a single SKU.

[2] In some older papers, Bulk/BW is used to mean Bulk (gm/cc). This was used by Scott Paper before it merged with Kimberly-Clark. The units are the same as bulk but the terminology is incorrect.

span between bonds makes the sheet stiffer. Of course, smoothness is important, but it is influenced by other factors including creping, calendering, chemical additives, fiber selection, etc. **In this paper, we focus only on strength as it relates to Bulk and Flexibility (Ref-6).** For an in-depth scholarly paper on the strength of paper, see (Ref-4).

Figure 1. Fiber Bonding



MEASURES OF STRENGTH

Tensile Strength

Tensile strength (Ref-1) for tissue is the peak load force to break a defined width of the sample under elongation. A typical unit would be grams force per unit width (gmf/mm). Tensile strength is important for runnability and the ability to hold the sheet together in use.

Tensile Index

At a given basis weight (weight of tissue/square meter), sheet Tensile Strength is the main driver of softness. When the sheet becomes stronger, it loses softness. When it gets weaker, it gains softness. Of course, this only holds true if the basis weight(g/sqm) remains constant.

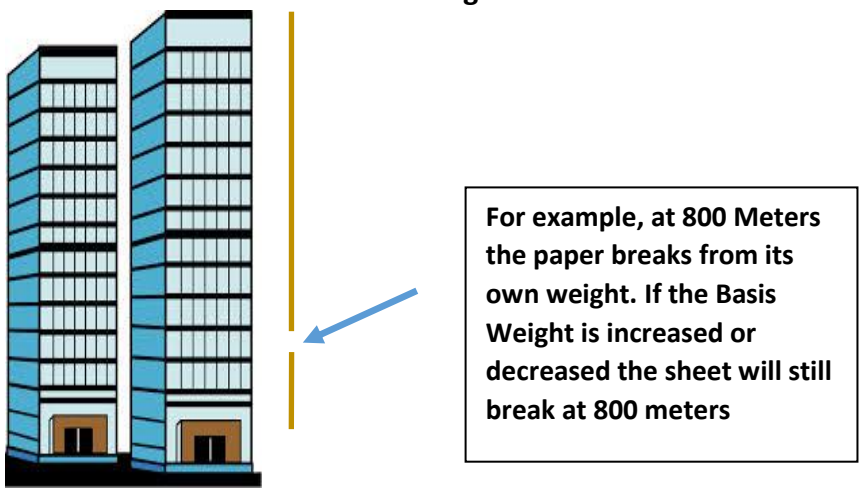
As the basis weight goes up, the strength goes up. When the basis weight goes down, the strength goes down. What actually drives softness is the ratio of strength-to-basis weight, which we express as the **Tensile Index** defined below**:**

$$\boldsymbol{Tensile\ Index(Meters)} = \frac{\boldsymbol{Tensile\ Strength}}{\boldsymbol{Basis\ Weight}}$$

Note that the unit of measure for Tensile Index is **Meters**[3], which is a unit of length. Unit of length often confuses people because it is not clear how length relates to tensile. One way to explain it is to consider a long length of paper draped over the wall of a tall building as shown in Figure 2 below. If the basis weight goes up, the overhanging weight (force) goes up, but then the strength increases in proportion. Therefore, the Breaking-Length remains constant because the structure, bonding and fiber strength remain the same.

[3] See Appendix III for a derivation of the units.

Figure 2.



In some parts of the world, Breaking-Length is referred to as "Bond Density". Appendix I provides an an alternative overview which may help to understand how Bond Density relates to the Tensile Index concept.

Geometric-Mean Breaking-Length, GMBL

For hand-sheets, the Tensile Index serves its purpose because hand-sheets are non-directional. However, tissue machines make paper that is highly directional. So, the MD Tensile and CD Tensile must be combined in some way. One way to do this is to simply take the **arithmetic mean** (average) of the MDT and CDT tensile given by:

$$\textbf{Tensile Index(Meters)} = \frac{(\boldsymbol{MDT+CDT})/\mathbf{2}}{\boldsymbol{BW}} \cdot \boldsymbol{c}$$

Where ***C*** is a constant.

Another approach is to take the **Geometric-Mean** of the MDT and CDT given by (MDT x CDT)$^{1/2}$ and divide this value by the basis weight as shown below:

$$\text{Geometric-Mean Tensile (GMBL)} = \frac{\sqrt{(\boldsymbol{MDTxCDT})}}{\boldsymbol{BW}} \cdot \boldsymbol{c}$$

Tables 1 and 2 show the Arithmetic Mean and Geometric-Mean as the MDT/CDT ratio changes**. <u>Notice that the Arithmetic mean remains constant as the ratio changes.</u>** Moreover, even when the CDT reaches zero, the mean is still the same at 750. Although, of course, with zero CDT the sheet would have no strength to make it through the converting process and the product would also fail in use.

<u>In contrast, when the MDT/CDT ratio changes shown in Table 2, the Geometric-Mean also changes</u>. Moreover, when the CD tensile goes to zero, the Geometric-Mean Tensile also goes to zero. This result more accurately represents the overall strength of the sheet. Based on this analysis, the Geometric-Mean is the preferred measure for the Tensile Index for machine samples and is abbreviated as **GMBL,** which stands for **Geometric-Mean Breaking-Length.**

Note that c is a constant. For example, if MDT and CDT tensiles are in units of gf/50 mm, the conversion constant c is 20 to give Meters. See Appendix 3 for the conversion calculation.

Table 1.

$$ARITHMETIC\ MEAN = \frac{(MDT+CDT)/2}{BW} \cdot c$$

MDT	CDT	MEAN
1000	500	750
1200	300	750
1400	100	750
1500	0	750

Table 2.

GEOMETRIC-MEAN $$GMBL = \frac{\sqrt{MDT \cdot CDT}}{BW} \cdot c$$

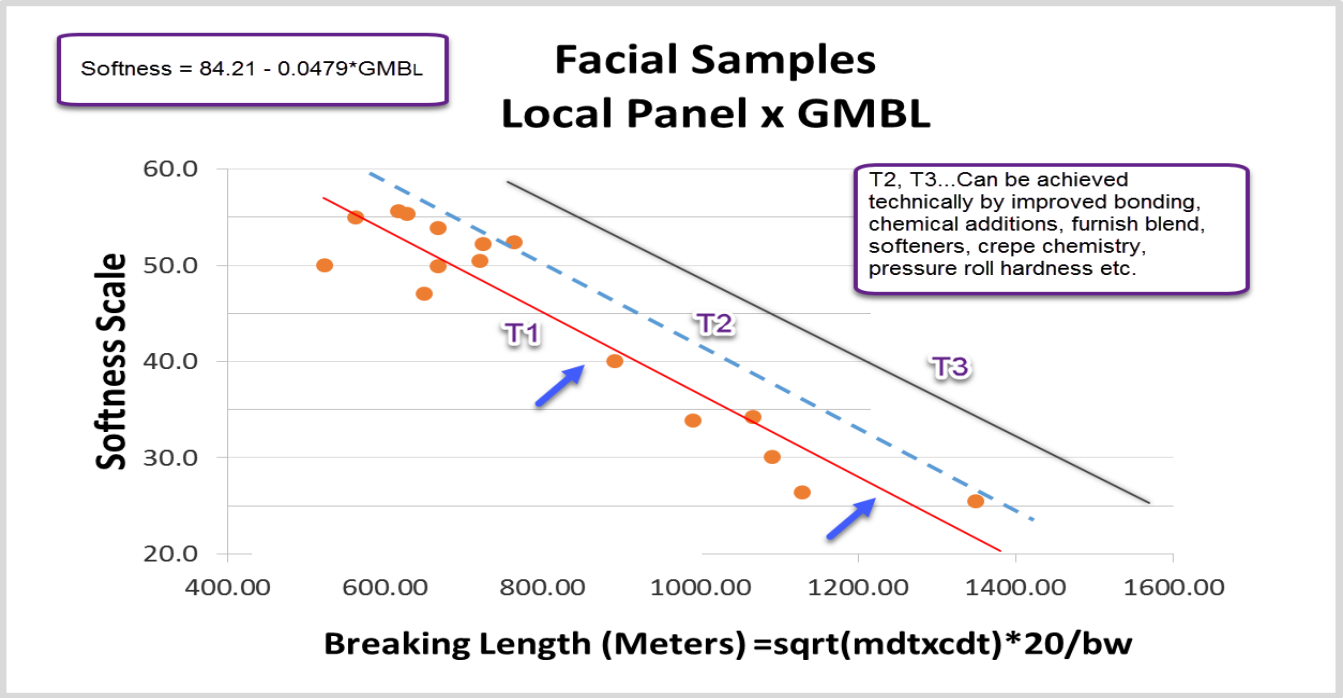
MDT	CDT	MEAN
1000	500	837
1200	300	600
1400	100	374
1500	0	0

Throughout the rest of this paper, I refer to the Tensile Index as **GMBL** for Geometric-Mean Breaking-Length.

GMBL IMPACT ON SOFTNESS

Figure 3 shows a relationship between softness and the GMBL indicated by the solid red line through the data points. I was able to generate this relationship from a stable process where the refining energy and basis weight were adjusted over a wide range represented by the circles. This data does not represent the relationship for all variables. For example, the upper, dashed line shows similar data, but the fiber furnish contained a higher level of long fiber. Technology curve T3 may be reachable using other available technologies including dry strength resins, fiber mix, creping. Technical groups often refer to these relationships as <u>technology-curves</u>.

Figure 3. Effect of GMBL on Softness



<u>What's interesting is that most mills around the world do not track GMBL!</u> The assumption is that if the Basis Weight, MDT, and CDT are in specification, then the GMBL is within specification as well. As we will see, this may be a terrible assumption, which allows softness variation to increase – with a big impact on raw material consumption and costs. To further understand this problem, we need to look at a standard specification shown in Table 3.

Table 3 Property Specification

Limits	Definition
LRL	Lower Reject Level
LCL	Lower Control Limit-warning
Tg	Target
UCL	Upper Control Limit-warning
URL	Upper Reject Level
Tolerance	URL-LRL
S	Standard Deviation
M	Multiplier (2.0 for ~ 95% Confidence)
Offset	Small tweak up or down from target

As we saw earlier, GMBL depends on three independent properties: BW, MDT, and CDT. Each of these properties has a set of specification ranges as shown in Table 4 and 5. **Please note that Table 4 is completely identical to Table 5**. However, Table 4 highlights a case where the basis weight (BW) is at its lower reject limit (LRL) and with the MDT and CDT at their upper reject limit (URL). At these conditions, the GMBL is **1245** meters.

In contrast, Table 5 shows the case where the BW is at its upper reject level, and the MDT and CDT are at their lower reject limits. At these conditions, the GMBL is **861** Meters. There is a big difference between 1245 and 861!

Table 4. High GMBL (1245 meters)

VARIABLE	LRL	URL	M	Tolerance	S	Tg	Offset
BW	**17**	18	2	1	0.2	17.5	0
MDT	1200	**1600**	2	400	66.7	1400.0	0
CDT	500	**700**	2	200	33.3	600.0	0

Table 5. Low GMBL (861 meters)

VARIABLE	LRL	URL	M	Tolerance	S	Tg	Offset
BW	17	**18**	2	1	0.2	17.5	0
MDT	**1200**	1600	2	400	66.7	1400.0	0
CDT	**500**	700	2	200	33.3	600.0	0

The main point of the above discussion is to show that, although the BW, MDT, and CDT values are all within spec., the compound variable GMBL provides the opportunity for a perfect storm where the GMBL can become exceptionally high or low. In the above case, the GMBL varies by almost 36%. Another way to look at how a compound variable magnifies a derived property is to study Appendix II which shows a simple simulation demonstrating how a calculated variable can increase the variation as shown by the Coefficient of Variation calculation given by COV = (Standard Deviation*100/Mean).

Now, looking back to Figure 3 we can find the corresponding softness levels for the extreme GMBL values. We can see[4] that the softness projection for technology curve T1 is from 44 for GMBL 861 and approximately 28 for GMBL 1245. This difference 44 vs 28 on the softer scale represents a very large difference in preference for softness. How do we know this?

[4] Note blue arrows showing the range of Breaking-Length and associated softness.

Let me explain: If a panel was used to gather preferences for tissue product samples based on a magnitude scale using anchors (Magnitude, Confidence and Reaction Time) as shown in Table 6, the scale values can be related back to the anchors in the table. For a scale difference of 16 (44-28), a sample pair difference would have a magnitude difference of 6 which is a Moderate-to-Strong preference based on these anchors[5]. Another way to state this is that, even while the MDT, CDT, and BW are within specification, the softness preference between rolls can vary from Equal to Moderate or even Strong.

Table 6. Scaled and Anchored Paired Comparison Scale (Ref. 3). Panelists can choose intermediate values (2,4,6,8)

Scale Value	Magnitude Anchor for Preference	Confidence	Time(sec.)
1	Equal	Not confident	60
3	Just Noticeable	Somewhat confident	30
5	Moderate	Confident	15
7	Strong	Very confident	10
9	Extremely Strong	Extremely confident	5

IMPACT OF GMBL VARIATION ON SOFTNESS REJECTS

Because the extremes of the Breaking-Length were chosen, one might suggest that only a few rolls may be produced by chance. To explore the validity of this suggestion, a series of simulations were carried out to determine the impact of GMBL with a normal distribution. Please read on and I will explain it further in detail.

To explore the effect of GMBL variation on the number of softness rejects, I created a simulation in which each property (MDT, CDT & BW) was randomly varied (1,000 times) according to a normal distribution and the GMBL calculated along with the corresponding softness. I then plotted the data in run charts[6] shown in Figure 4. Note that the fundamental properties of BW, MDT and CDT are within specification with an expected number of outliers. The frequency of the GMBL appears in Figure 5 below, and from this graph, we can see that the GMBL ranged between 940 and 1175. Using Figure 3 again, we can map the GMBL to Softness. Figure 6 shows the simulated values for softness generated using the GMBL in Figure 5.

[5] Calculated from mean scores from 30 panelists

[6] Statistical Quality Control was introduced by Dr. Walter Shewhart in the 1920's at the Western Electric Company, which eventually became General Electric. A key component of SQC was to establish the statistical capability of a process to produce specific products. Run charts were introduced to graphically plot quality data versus time. The charts also contained the target, the statistical limits, and the reject limits to monitor conformance to the quality specifications. Dr. Shewhart believed that operators could more easily understand and react to graphical displays versus long strings of numbers. Eventually, run rules were established to give operators guidance in operating processes. These rules were needed because operators often overreacted to seemingly meaningful trends. SQC is now a mainstream strategy and has been adopted into such programs as Six-Sigma. See Reference 10 for an updated coverage of SQC

Figure 4. Variation in Basis Weight, MDT, CDT and GMBL (Norm. Dist.) with Softness Range 30-40

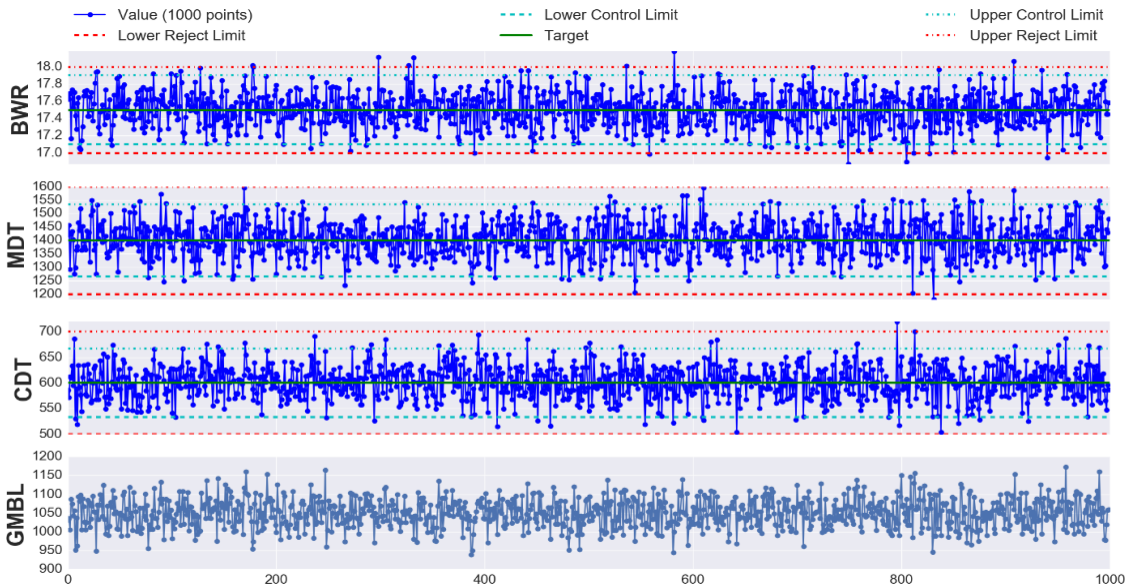


Figure 5. Distribution of GMBL

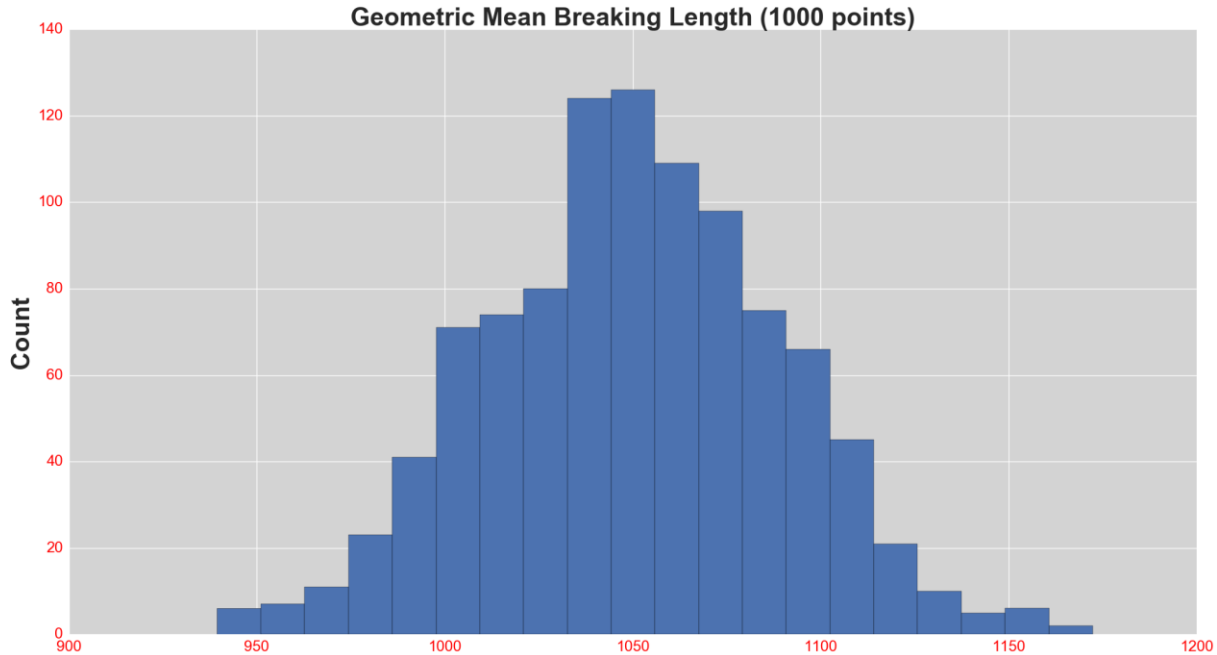
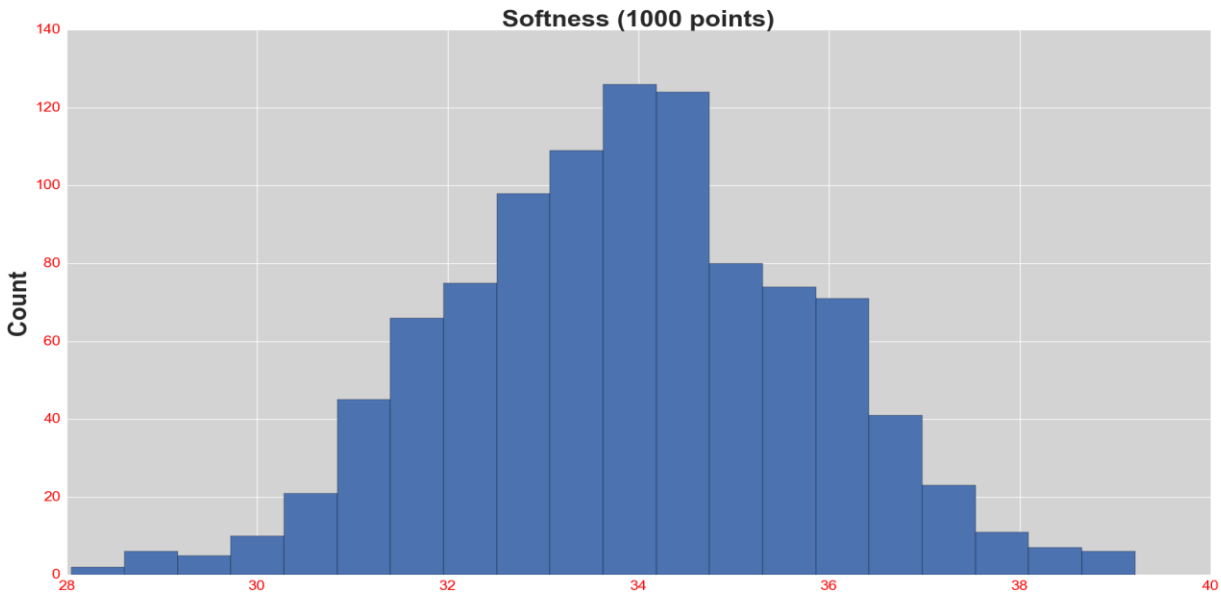


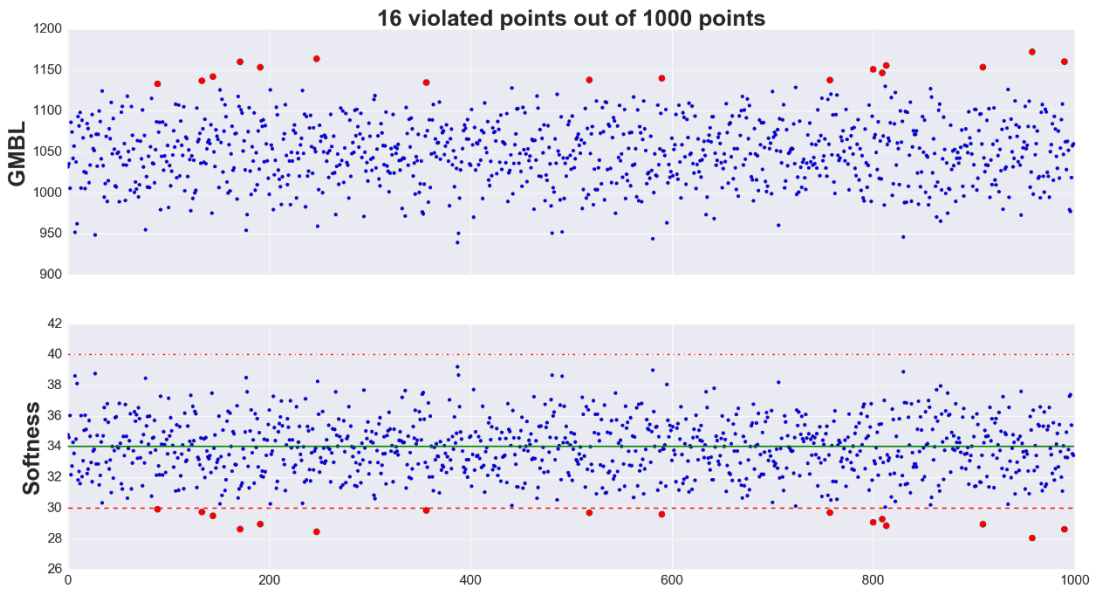
Figure 6 shows the variation in softness generated from the variation in GMBL according to Fig. 3.

Figure 6. Distribution of Softness from Normal Distribution of BW, MDT, CDT and GMBL



The GMBL and Softness run charts were then plotted from the simulation as shown in Figure 7 below. As shown, the GMBL is skewed to the high side making the softness skewed to the low side and out of specification

Figure 7. Run Chart of GMBL and Softness showing out of spec softness points. Large red dots indicate softness levels that are out of spec (16 out of 1000).



BAD PRACTICES CAN MAKE THINGS MUCH WORSE

The previous analysis clearly demonstrates how softness can be off track even though the MDT, CDT, and BW are all in within specification. In Real-life operation of a paper machine, things can get worse when it comes to softness variation.

For example, machines are often run within specification but operate with an intentional "offset" in an attempt to make savings or meet conflicting KPI's. For example, the basis weight may be set to run somewhat lower than the target to speed the machine while the strength is moved slightly higher to reduce sheet breaks. Again, the process is still within specification. Operators sometimes refer to these as 'offsets' or 'tweaks.'

To demonstrate the scale of the problem associated with 'tweaks', I increased the MDT and CDT very slightly above target, and the BW was reduced just below target. The actual offset is shown in Table 7 which is highlighted by the red arrow and red text.

Table 7. Tweaking of variables defining GMBL

VARIABLE	LRL	URL	M	Tolerance	S	Tg	Offset
BW	**17**	18	2	1	0.2	17.5	-.1
MDT	1200	**1600**	2	400	66.7	1400	+5
CDT	500	**700**	2	200	33.3	600	+2

Figure 8 shows the results of the simulation, **which preliminarily at least,** indicated that a few more rolls (2%) were slightly below reject level. **However, as we go through the data analysis and see how the tweak changes the GMBL, and therefore the softness scale, the impact is magnified and more negative than initially indicated.**

(Please note that figures 8, 9, 10 and 11 are the same as figures 4, 5, 6, and 7, except that the tweak has been added.)

Figure 8. Tweaked elements of GMBL

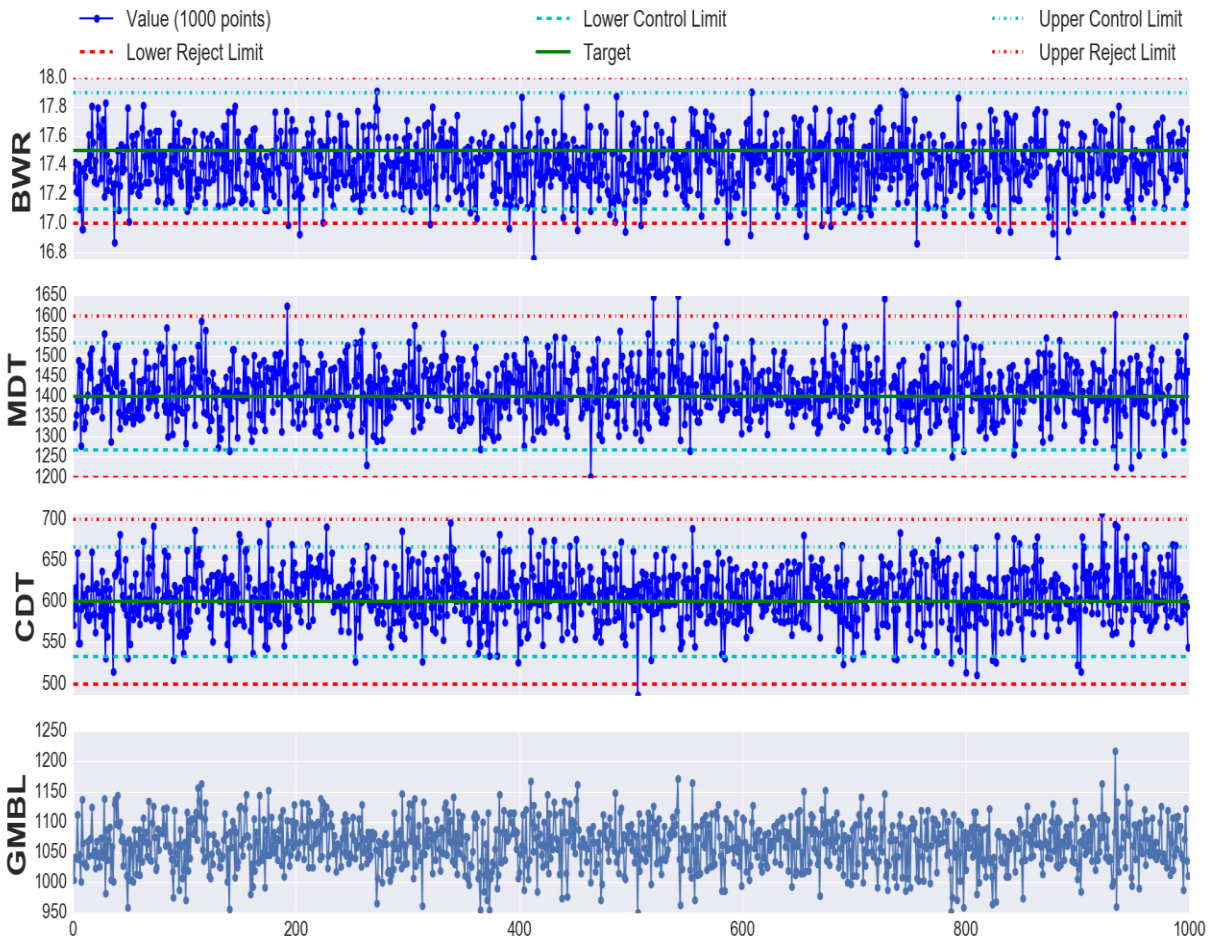


Figure 9. Distribution of GMBL for 'Tweaked' specifications.

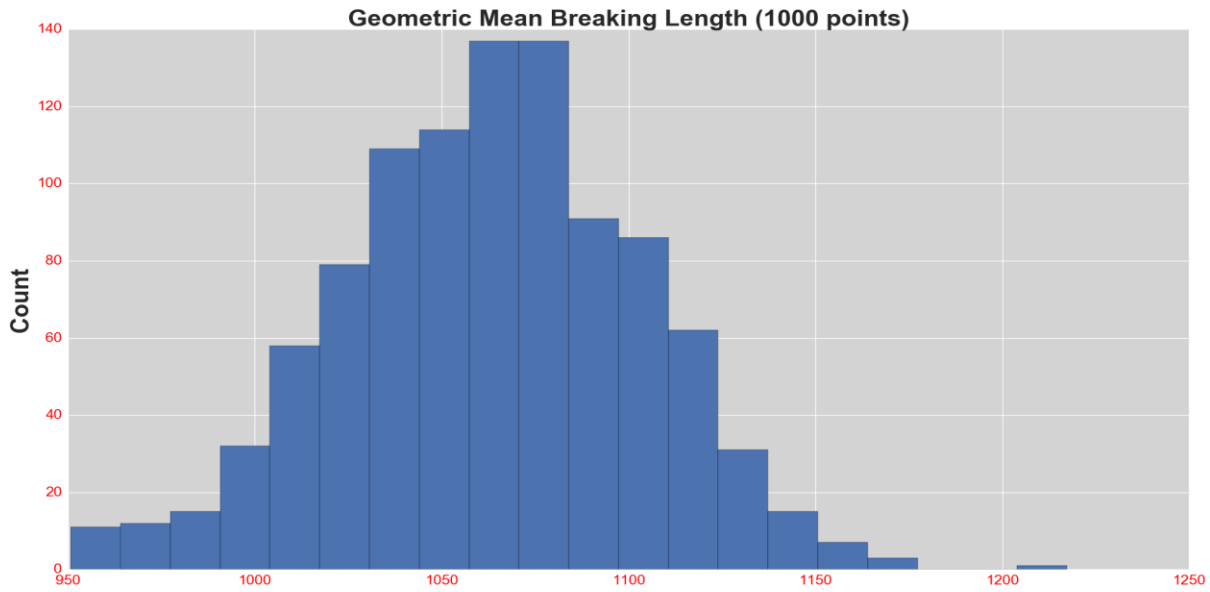


Figure 10. Distribution of 'Tweaked' Softness

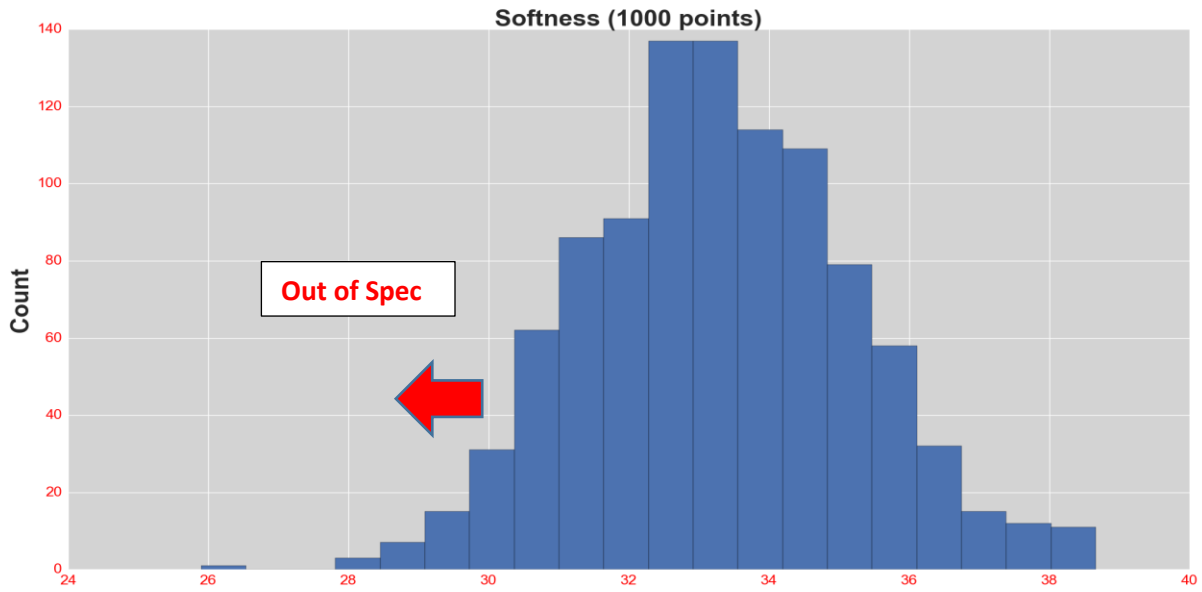
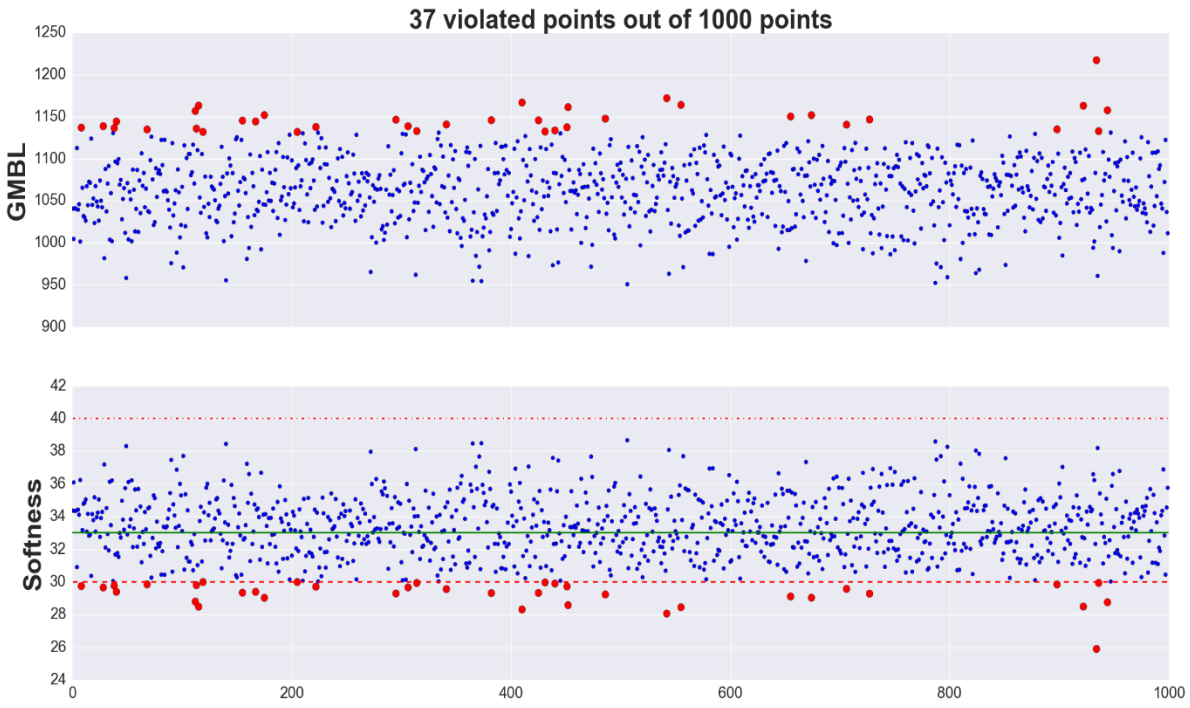


Figure 11. Slight 'Tweak' shows 37 rolls out of 1000 rolls out of spec on softness



As Figure 11 shows, almost twice as many rolls (16 vs. 37) are out of spec compared to the non-tweaked sample. This result highly suggests that run charts (Ref-10) should be established to track GMBL vigilantly to give the most powerful insight into what is actually happening. (See again footnote 6, on page 8 above).

CONTROLLING SOFTNESS

Over the years, many companies have developed internal methods to measure and control softness including:

- Creating a set of softness standards which QC uses to compare to current production.
- Controlling all output properties using SQC methods including run charts and run rules.
- Developing mechanical devices to measure softness (Ultrasound, Kawabata, TSA, …)
- Controlling all input variables to stabilize outputs (Centerlines).

Here follows a short discussion each of these.

Creating Softness Standards

Creating a set of softness standards to compare to production samples has been a common way to try to control softness. Market Research usually selects a range of rolls to represent the spectrum of product in the market. Market Research or the QC department then selects a group of panelists to sort the samples by rank ordering the samples using paired comparisons. For each sample pair, panelists select the preferred sample and allocate a score

of 1. By default, the less preferred sample gets a 0. After a panelist compares all pairs, their votes are tabulated. Softness values can be assigned a number based on position. Alternatively, the percentage of votes can be allocated to each standard. Numerous problems develop using this approach including:

1. Samples selection (Market or Production)
2. Instructions to panelists are inconsistent.
3. Simple ranking methods often create large gaps in the standards.
4. Most panel procedures lack panelist diagnostics to determine consistency in judgment and repeatability.
5. A method to systematically replace standards is often absent. This task is usually left up to lab managers that may not represent the market. Improperly placed standards also result in standards drifting and sometimes reversed. (e.g. 60>70)

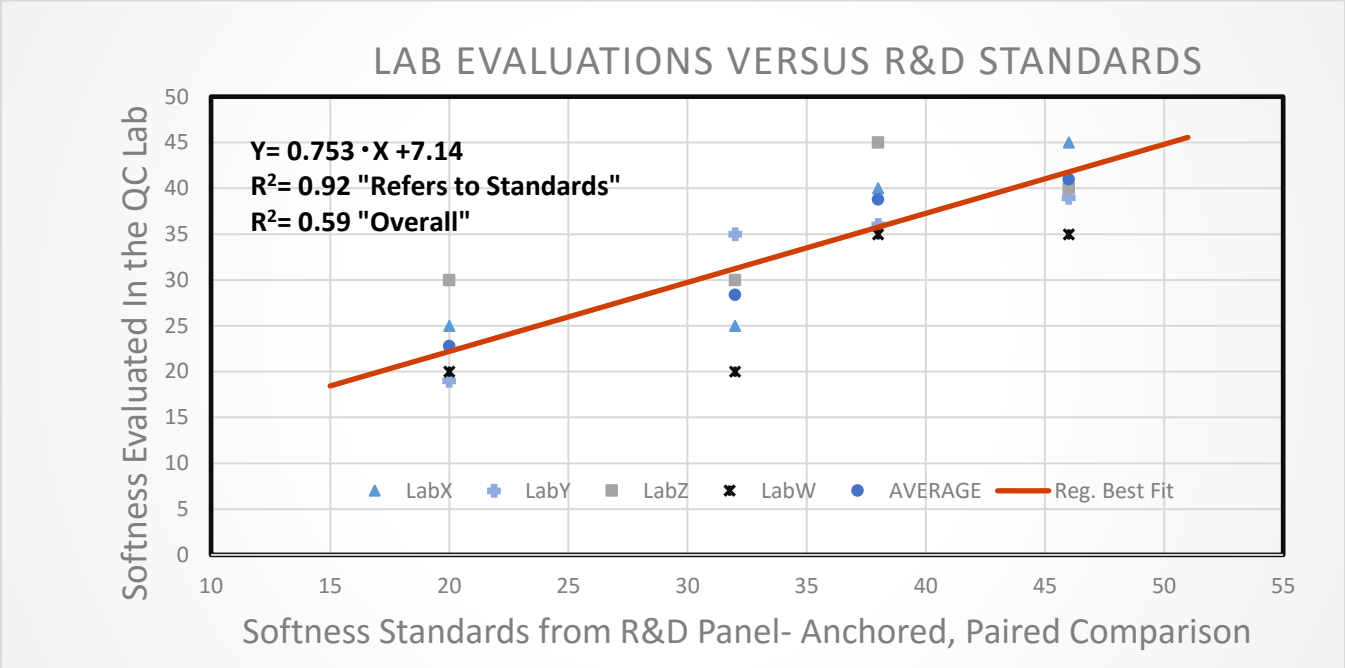
To demonstrate these points, we can examine a lab-to-lab comparison trial. In this trial, four softness standards were selected with the following softness levels (20, 32, 38 and 46). These values were obtained from two softness panels (Ref-3) with fifteen panelists in each panel for a total of thirty panelists. The panel diagnostics for these panels, which included consistency, precision, and accuracy, was very high.

For four weeks, one of the standards was given to the lab (randomized by shift) to evaluate for softness. At the end of the trial, the results were evaluated.

Figure 12 shows the results of the lab-to-lab comparison of softness standards. In this graph, the four separate labs (LabX, LabY, LabZ, and LabW) are shown. Each lab had its own personnel. Each lab covered three shifts.

On average, the standards correlate well with the overall average (blue circles) of the lab personnel (R^2=.92). However, the variability between the lab personnel and the standards is quite high with an R^2=0.59. In some cases, lab personnel differed as much as 15 points in softness.

Figure 12. Lab Results Versus Standards



Another way to demonstrate the variability of panelists is to examine the scores given in scaled paired comparison panels. Table 8 shows a portion of a softness panel data sheet. Each row summarizes the votes between each sample pair. The total score or votes in each row are 30 which equals the number of panelists. In row one sample A is compared to B. We can see that five panelists voted ”1” to indicate ‘no preference’. In the same row, we can see that nine panelists indicated a ‘just noticeable’ preference for B, while five other panelists voted “7” indicating a ‘very strong preference’ for B. In row four the samples D and E are compared showing the vast disparity of opinions. This disparity might suggest an opportunity for segmentation!

Table 8. Softness panel paired-comparison scores showing wide variation in opinion on softness preference(Ref-3)

Box Plot | Regression Chart | Standard View | Alpha for λ max 0.25 | λ max : 9.01 | R value for scale 1.0 | Save to excel file | Refresh

Pair Data for 30 Panelist(s) | Classic Raw Score | Classic Logged Raw Score | Analysis Result | Panelist Performance | ANOVA

No.	Code	%	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	%	Code
1	A	16	0	0	0	1	0	0	1	2	5	1	9	2	3	0	5	1	0	84	B
2	B	10	0	0	1	0	0	1	1	0	0	1	1	2	5	0	10	3	5	90	C
3	C	93.1	4	2	11	1	5	0	3	1	1	0	1	1	0	0	0	0	0	6.9	D
4	D	64	0	2	2	1	5	0	4	2	5	0	3	1	2	0	2	1	0	36	E

Property Standards

Another strategy to control softness variation is to set the desired specifications for the product and then set the operating parameters such as MDT, CDT, BW, and THICKNESS. The QC lab or a back tender checks the softness by comparing the product to previously determined softness standards. Unfortunately, this method suffers from all the problems of the previous method because the judgment of a single person is involved. Also, and as previously discussed, the individual properties can be within specification, but the GMBL can vary, driving softness out of specification.

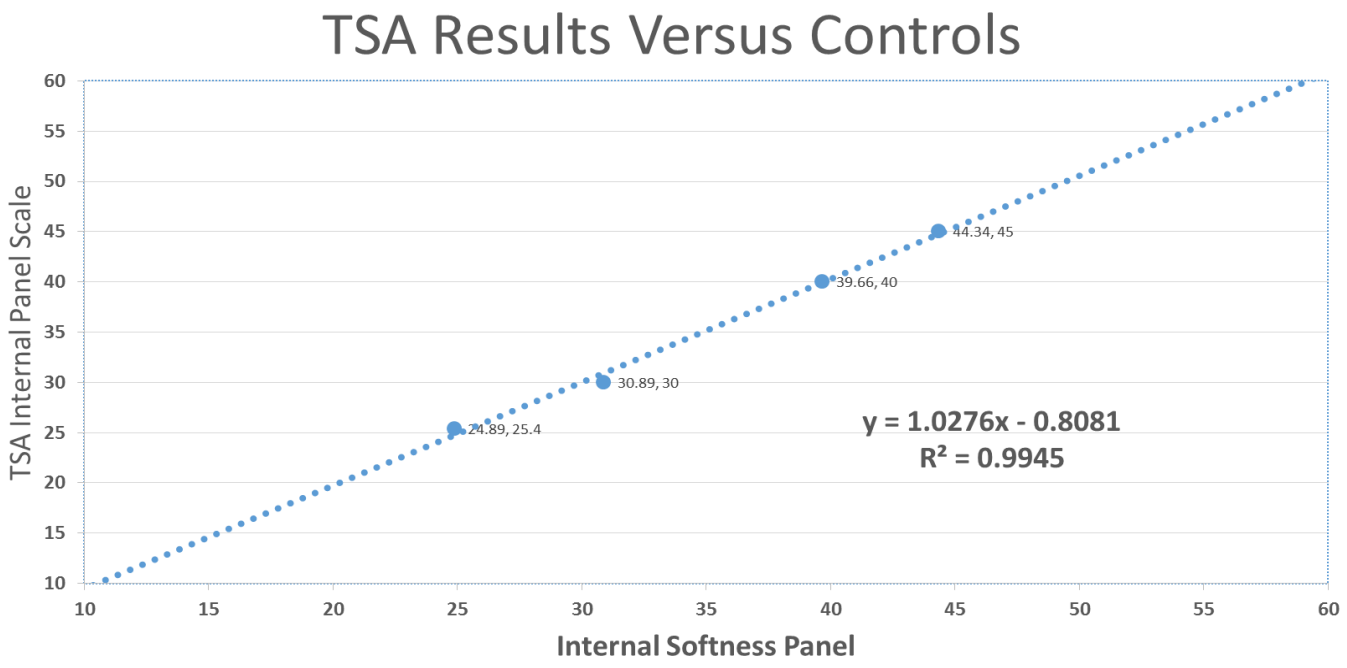
Developing mechanical devices to measure softness (TSA, Ultrasound, Kawabata…)

For over thirty years, many researchers have tried to develop a single instrument or a series of tests to predict softness to remove the subjective preferences of panelists. These methods included ultrasonic transmission rates, surface profilometers, multiple precision tests (Kawabata), combined flexibility, compressibility, friction testing, etc. These methods all produce correlation coefficients from 75 to 85 percent which was too low for good control. Also, these methods do not accurately predict softness across all regions of the world, especially when comparing mature to emerging markets.

Recently, the Tissue Softness Analyzer (TSA) from Emtec (Ref-2) has made some novel improvements on past attempts to quantify softness. One reason for the improvement is that this instrument focuses on measuring the main individual components of human hand feeling measured by simulating the sensory physics of the hand (Ref-7) within a single technical instrument. Also, the Quality Department can tune their TSA instrument to local markets. This ability is quite significant because softness is perceived differently around the globe. The Quality or Production department can also tune the instrument for different grades or sku's. Finally, the TSA can be used to measure the individual components of softness which supports process optimization. Figure 12 shows the remarkable accuracy the TSA has in matching the softness from a professional panel[7].

[7] Frameworxs Analytics has no business relationship with Emtec, the company which makes and sells the TSA.

Figure 12. Correlation of expert panel values versus TSA



Controlling all input variables to stabilize outputs (Centerlines).

Several decades ago, Edward Demming supported Prevention versus Inspection to control processes to make quality products consistently at the lowest cost. Rockwell International (Ref-8) and Kimberly-Clark have both focused on a process control strategy named Centerlining which promotes a prevention strategy. The essential elements of this strategy include:

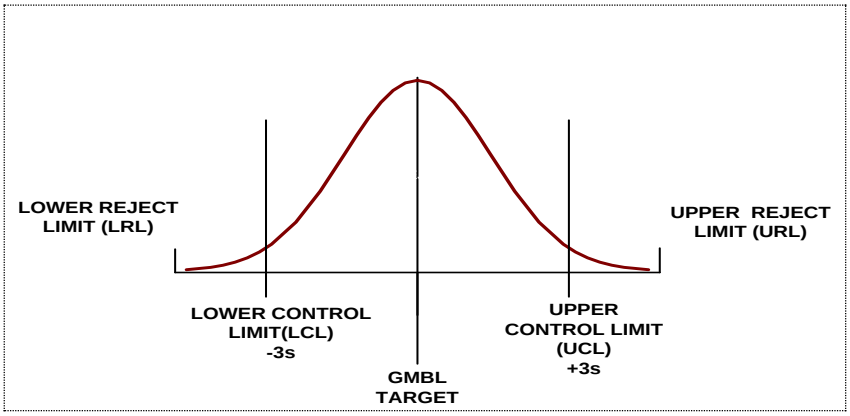
1. Identifying all process variables Critical to Quality (QTC)
2. Fixing as many of these variables as possible but routinely monitoring them to make sure they have not changed.
3. Optimizing key process variables to achieve SKU specifications and setting operating ranges for each.
4. Prioritizing actions (Shut down, Correct in Time Limits, etc.) based on Branding, Safety, and Environmental issues
5. Rewarding Production for keeping the process settings in Centerline ranges.

This prevention strategy has worked well. However, it is very data intensive and requires enormous amounts of analysis to be successful. Fortunately, faster and better data management tools are evolving rapidly along with Data Analytics to eliminate these roadblocks.

Reducing Variation to Reduce Costs

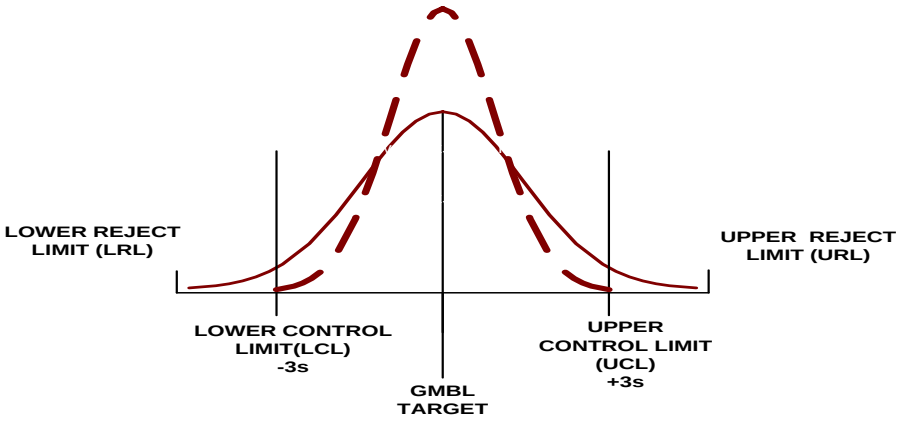
Once softness variation is reduced by strictly controlling GMBL and using TSA measurements, process variables can be systematically explored to further reduce softness variation. Achieving this goal has huge financial implications. For example, consider Figure 13 which shows the variation of GMBL along with the upper and lower reject and control limits. Remember, as the GMBL gets higher, the softness goes lower.

Figure 13. Normal Distribution of GMBL with upper and lower Control and Reject Limits



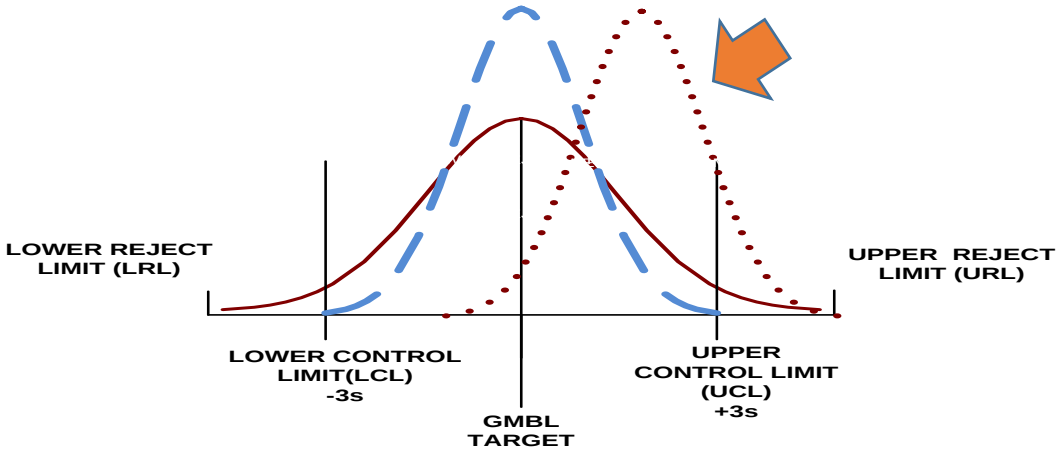
Now consider Figure 14 showing a reduction in GMBL variation (Shown as a dashed curve). In this case, more product will be closer to the softness target and fewer extreme variants will exceed the Upper Reject Limit for softness.

Figure 14. Effect of reduced variation in softness through improved monitoring and process optimization



Once the variation in softness is reduced as shown by the dashed bell curve above in figure 14, a big opportunity arises to reduce the Basis Weight. Because the Basis Weight is in the denominator of the GMBL equation, the lower basis weight will increase the GMBL, shifting the dashed curve to the right as shown in Figure 15. However, because of the narrower range of softness, very few rolls will exceed the Upper Reject Limit.

Figure 15. Effect of decreasing basis weight.



Measuring the cost savings of a basis weight reduction[8]

Reducing Basis Weight provides the opportunity to:

1. Reduce fiber = Cost and Cash Flow Savings
2. Increased machine speed = Volume Increase, Revenue Gains
3. Reduce Steam and Gas energy consumption costs = Cost Savings
4. Reduce chemical consumption = Cost Savings
5. Better cover of fixed costs = Increased Profitability

Additionally, if you have problems with sheet breaks, the tensile strength can be increased to improve the sheet strength, thus reducing breaks while still not exceeding the Upper Reject Limit for softness.

CONCLUSIONS

1. The Geometric-Mean Breaking-Length (GMBL) is a great tool that tissue makers can now easily use, due to recent developments in softness testing and data analytics.

2. Even if MDT, CDT, and BW are in specification, the GMBL can push softness out of spec.

3. Setting up softness standards as a control measure is difficult because people vary widely in their perceptions of softness and standards are difficult to replace. A rigorous scaled, paired comparison procedure with panel diagnostics can improve this. Also, a properly tuned TSA provides a much more efficient way to track softness. However, preliminary benchmarking panels need to be performed to tune the TSA properly to the market and each SKU in production.

(continued on next page)

[8] In a similar manner, reductions in the variation of Bulk (cc/g) can lead to significant cost savings.

4. Tracking GMBL is much better than tracking BW, MDT, and CDT independently and provides a way to reduce softness variation. If the softness variation can be reduced, then it is possible to reduce the basis weight and still achieve quality while reducing cost.

5. QC can track GMBL to reduce softness variation. Reduced variation allows for basis weight reductions that can lead to substantial savings in fiber, chemicals, and energy.

6. Geometric-Mean Breaking-Length is highly correlated to softness which can be represented with a technology curve. However, if the technology of the process shifts, the softness will shift to a new technology line. Typical technology shifts include furnish changes; softening agents; creping chemistries; refining technology; drying strategy; etc.

RECOMMENDATIONS

1. Calculate GMBL and establish upper and lower control, and reject limits for GMBL for each grade. Include GMBL in QC run-charting.

2. Establish a professional, scaled comparison panel method Ref (3) with at least 10 panelists to establish properly spaced standards to tune the TSA for production and to benchmark the market.

3. Consider using a TSA from Emtec to routinely and consistently measure softness in your factory to guide efforts to reduce softness variation.

4. Once the variation in softness is reduced, you should attempt to reduce basis weight as this can provide cost savings yet not exceed lower reject levels for softness.

5. Communicate to production people the impact of GMBL and it's importance in maintaining consistent softness.

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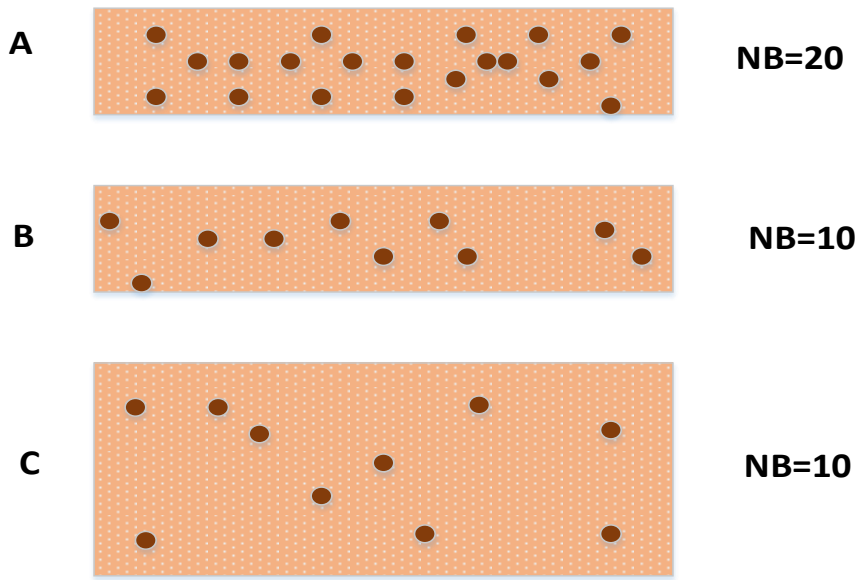
APPENDIX

I. BOND DENSITY

Another way Breaking-Length is described in some regions of the world is Bond Density.
For example, below are three paper sheets labeled **A**, **B** and **C**. These represent three sheets of paper in cross section. The height represents the basis weight. **A** represents a sheet with a nominal 100 grams/sqm. **B** is 100 grams/sqm and **C** is 200 grams/sqm



The brown dots in each sheet represent bonds between fibers that provide strength to the sheet. In sheet **A** there are 20 bonds. In sheet **B** there are only 10 bonds. We can see sheet **A** should be twice as strong as **B.**

To calculate the Breaking-Length for sheet **A,** we would divide the number of bonds by the basis weight of 100. Therefore, sheet **A** would have a Breaking-Length of **BL**= 20/100 = 0.2. Sheet **B** would have a Breaking-Length of 10/100= 0.1. Therefore, sheet **B** has a lower Breaking-Length than **A**. We might also guess that sheet **B** would be softer than sheet A.

Sheet **C** has a basis weight of 200 with only 10 bonds. Therefore, the Breaking-Length of **C** is 10/200 = 0.05, so **C** would have a much lower Breaking-Length than **A** or **B**. Visually you might see that the softness would be higher than **A** or **B**.

II. VARIATION INCREASE WITH COMPOUND VARIABLES

Event	MDT	CDT	BW	GMBL
1	1	1	1	1.00
2	1	1	2	0.50
3	1	1	3	0.33
4	1	2	1	1.41
5	1	2	2	0.71
6	1	2	3	0.47
7	1	3	1	1.73
8	1	3	2	0.87
9	1	3	3	0.58
10	2	1	1	1.41
11	2	1	2	0.71
12	2	1	3	0.47
13	2	2	1	2.00
14	2	2	2	1.00
15	2	2	3	0.67
16	2	3	1	2.45
17	2	3	2	1.22
18	2	3	3	0.82
19	3	1	1	1.73
20	3	1	2	0.87
21	3	1	3	0.58
22	3	2	1	2.45
23	3	2	2	1.22
24	3	2	3	0.82
25	3	3	1	3.00
26	3	3	2	1.50
27	3	3	3	1.00
Average	2	2	2	1.17
Stdev	0.83	0.83	0.83	0.83
COV	0.42	0.42	0.42	0.71
Expansion in Variation	%	14.84		

The MDT, CDT, and BW were allowed to only have values 1,2 or 3. The GMBL was calculated by GMBL=Sqrt(MDTxCDT)/BW.

All combinations were created and the GMBL calculated for each.

The average, standard deviation and Coefficient of Variation (COV) calculated for each measure. As shown, the COV measures the relative or normalized variation.

The COV for GMBL is about 15% greater than any of the individual measures <u>demonstrating how much GMBL can influence Softness variation.</u> See blue arrow.

III. UNITS FOR TENSILE INDEX (Example)

$$\text{Tensile Strength} = \text{gmf}/50\text{mm}$$

$$\text{Basis Weight } (\frac{\text{grams}}{\text{sqm}})$$

$$\text{Tensile Index} = \frac{\text{TensileStrength } (\frac{\text{gmf}}{50\text{mm}})}{\text{BasisWeight } (\frac{\text{grams}}{\text{sqm}})}$$

$$\text{Tensile Index(meters)} = \left(\frac{\cancel{\text{gmf}}}{50\cancel{\text{mm}}}\right) \text{x} \left(\frac{\cancel{\text{sqm}}}{\cancel{\text{gram}}}\right) \text{x} \left(\frac{10\cancel{\text{mm}}}{\cancel{\text{cm}}}\right) x (\frac{100\cancel{cm}}{\cancel{meter}})\text{x}20$$

BIOGRAPHY

Dr. Wes McConnell is CEO of Frameworxs Analytics which focuses on Process Analytics and Sensory Science Software. He is one of the world's leading experts on tissue softness, having worked for over 40 years in the Tissue and Non-woven businesses beginning with Johnson & Johnson (4 years); Scott Paper (17 years); Kimberly-Clark (7 years); Buckman Laboratories (5 years); and Asia Pulp and Paper (9 years).

Dr. McConnell has 12 US Patents including Smart Dispenser Technology; GATS Absorbency Tester; MEBS Technology; Compressed UCTAD towels; and Low Strike through Tissue.

At KC he held the position manager for the AFH Market Research team as well as the Sensory Lab. In addition, he led the KC Away From Home R&D team for the development and commercialization of the UCTAD tissue process in Owensboro, KT.

Dr. McConnell now lives in Seattle, Washington. He can be reached at wesinpa2002@frameworxs.com

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