Desirability Concept : For Addressing Process Variability And Quality Complaints in Paper Industry

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ABSTRACT

The concept of D (desirability) proved useful in developing the compositions and manufacturing processes for better quality writing - printing paper. For mills manufacturing a wide variety of paper, Desirability concept can be used for addressing process variability to achieve desired process optima, and quality related customer complaints.

Having transformed the several measures of quality to the dimensionless scale of desirability, it is now possible to combine these several d's (i.e.desirability of GSM, Bulk, Burst, Brightness, Cobbs etc.) by any of the operations of arithmetic, to measure the over all desirability, D, of the paper. The mathematic model analogous to the customer reactions based on properties of paper, is the geometric mean of the component desirabilities (d's). Finally the case study reveals how for a commercial product like paper, the suggested D-scale is the inherent value of physical properties of paper to the customer.

INTRODUCTION

All the organizations, what-ever be their classification into sectors, are ultimately maintained by their customers and customer service is vital for their growth in a competitive economy. The national economy will also hinge on how well the industries in the liberal economy perform in the area of customer service. Organizations in manufacturing sector may have their own customer service departments in their distributive chain, through which they serve their cusotmers. Generally the customer service has two faces - one that serves the ultimate customers and the other that looks after the needs of intermediate customers.

With the growing requirements of the physical attributes in the paper demanded by the customers. It is becoming more difficult for a manufacture to handle customer complaints. Complaints regarding poor-brightness, shade, bulk, and strength properties are not uncommon in commercial grade paper. But the situation becomes critical when customers ask the company for heavy rebates on poor quality. It is not always that the manufacture agrees to the redemption

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of such demands of the customer for the maintenance of good customer relations. Thus for the better administration of such critical situations, need necessitates the paper manufacture to have a system that can justify the customer demand along-with the extent of genuinety of his complaint.

Traditionally the composition of steel and polymers is optimized by using the desirability concept. the comparative estimation of quality of different composite steels and polymers are determined on the basis of individual quality parameters desired by the customers. Desirability function technique is a proven technique to optimize industrial processes and to prepare a good composition of final product.

With the latest advancements in pulp & paper industry it is important for a competent manufacturer to have a keen observation on what quality parameters are demanded by the customers and what he is furnishing to its valuable customers. It is nearly always desirable from the manufacturer's stand point to stay not only with-in the specification limits but also some distance away from them to avoid substandard quality due to the inherent process variability. Furthermore because of sampling & testing unprecision, it is quite impossible to seprate quality into two unequivocal groups, the acceptable and the unacceptable product.

Using case study method, attempt have been made by us to judge the customer's complaint by comparing - the manufacturer rating and the customer rating of Maplitho White Paper. The desirability function concept was applied to see- the Quantitative view of Quality and Desirability of the paper supplied to the customer.

THE DESIRABILITY FUNCTION

Process optimization concerned with several responses (as that of paper, where the consumer is looking for properties like gsm; size; strength properties like tear, tensile, burst, folding endurance; Cobb 60 bulk, finish, porosity, Air permeability etc. & Optical properties like opacity, brightness etc.) is usually reduced to the optimization procedure utilizing one criterion with inequality and equality constraints. Depending on the shape of the response surface and the character of the constraints, there exist a number of optimization methods such as lagarange multipliers, linear and non-linear programming, ridge analysis etc. These methods are disadvantageous in that the associated computations are very complicated. For example, if one tries to describe the response surface using second order polynomials, a set of simultaneous non-linear equations must be solved in order to find the conditional extremum with the help of lagrange multipliers.

A useful approach to the optimization of process with several responses is the concept of over-all desirability D. This concept deals with a dimensionless scale or scale to which the measured responses (i.e. GSM, Tear..... Cobb) are transformed so that they may be interpreted in terms of quality and desirability for any specific application. For a commercial product such as paper it is suggested that such a scale is the inherent value of these properties to the customers.

Although many such scales are possible, a useful scale ranges between 0.00 and 1.00 such that d=0.00 corresponds to a completely undesirable level of quality of the product and d = 1.00 corresponds to a completely acceptable level of quality, i.e. an improvement in quality would serve no useful purpose.

Desirability Value (d)	Description of responses (quality equivalents)
0.80 - 1.00	Acceptable and excellent
0.63 - 0.80	Acceptable & good
0.37 - 0.63	Acceptable but poor
0.20 - 0.37	Borderline
0.00 - 0.20	Unacceptable

Because of the mathematical treatment chosen, it is rational, convenient and practical to assign a desirability value of 0.37 to any property at its specification value, maximum or minimum, assuming that realistic specification limits exist for this property. The number 0.37 is approximately 1/e where is the base of natural logarithm.

A second such useful landmark is the value of a property corresponding to the best commercial quality (existing or anticipated) for which a desirability value of 0.63,

$d = 1 - 1/e = 63$ is assigned.

The simplest sort of transformations of a given response to the scale of d is that in which there exist lower and / or upper specification limits. The latter are the sole and unalterable criteria of quality, outside these limits the value of d is 0.00, and within, the value

of d is 1.00. In the case of a one sided specification the value of d is expressed as

$$d = \begin{cases} O\ y & < y\ min \\ 1\ y & \geq y\ min \end{cases}$$

With the upper specification limit, the value of d is determined in alike manner. When the given property has a mid specification, e.g. paper moisture 4.5% <Y<5.5% the value of d is given by

$$d = \begin{cases} 0, \ y & < ymin, \ y > ymax \\ 1 & ymin <= y <= ymax \end{cases}$$

It is nearly always desirable from the manufacture's stand point to stay not only within the specification limits but also some distance away from them in order to avoid substandard quality due to inherent process variability. (See Fig. 1.0 and 2.0)

Furthermore, because of sampling and testing unprecision, it is quite imposssible to separate borderline quality into two *unequivocal groups* the acceptable and the unacceptable product.

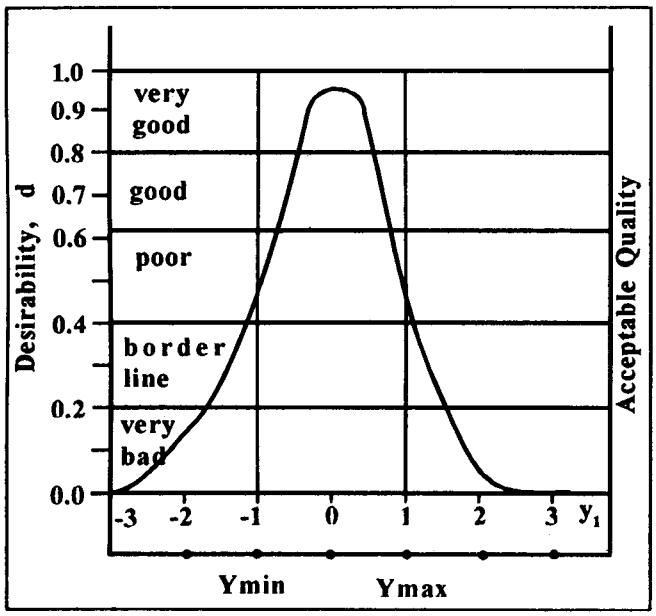

Fig. 1.0 Graphical representation of a midspecification

Thus the transformation of y to d obeys more sophisticated laws in the general case. If midspecification is of the form Ymin < = y < = Ymax, then the measured response y is transformed in to the scale of d by using the following expression.

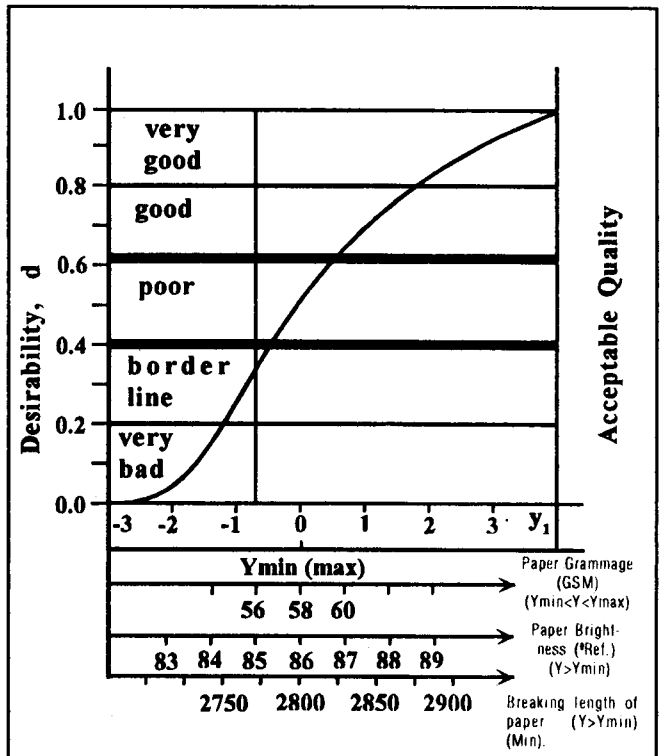

Fig. 2.0 Graphical representation of one sided specification and Desirability (d) versus y' response relationship.

$$d = \exp [- (|y'|)^n]$$

where n is a positive number (O<, n< ∞) not necessarily an integer

and

$$y^1 = 2y\ (Ymax+Ymin)/(Ymax-Ymin)$$

The exponent n may be calculated by selecting a value of y = d (perferably in the range 06 < d<0.9), finding the corresponding and substituting in the equation

$$n = Loge\ [loge\ (1/d)]/loge|y|'$$

By relating the steepness of the desirability (transformation) curve to a given check point one can take into account the importance of some specific properties of the product. For such properties, The value of n is of greater importance : a mall variation of the property in the vicinity of the specification limits will correspond to an abrupt change in the desirability value. The exponent determines the slope of the curve, and as n becomes large, the curve approaches the

limiting case of d = 0.00 outside the specification limits and d = 1.00 within limits. if there is no specification, it is good practice to statistically test the value of n, using the selected range of the values of y and their corresponding d's

In case of a one-sided specification such as y < ymax or y> ymin, one can utilize another exponention relationship to tranform y into d

d = exp [-exp (-y') 0.2 <d<0.8

and y' = bo+b1y

The two constants, bo and b1 are determined by assigning to two values of y the corresponding values of d (preferably in the range 0.2 <d<0.8).

A nonlinear transformation of y into y' is applicable to the case when a given property is critical, when the boundary conditions cannot be described and when a small change in the property in the vicinity of the specification limit results in a sudden variation of the desirability value. In practice, one often deals with one sided specification. (e.g. ISO specification for burst factor of the paper)

Having transformed the several measure of quality to the dimensionless scale of d, it is now possible to combine several d's by any of the operations of arithmetic to measure the overall desirability, D, of the product. A basic premise is this - if any one property is so poor that the product is not suitable to the application that product will not be acceptable (D=O), regardless of the remaining properties. It is also true that customer reaction to a product is based very largely on the less desirable properties of that product because these are the focus of potential trouble.

The mathematic model anologous to these psychological reactions is the geometric mean of the component d's

$$D = k\sqrt{d_1, d_2, \ldots\ldots d_k} = (d_1, d_2, \ldots\ldots d_k)^{1/k}$$

Like any response in the process, D can be subjected to all computational operations. During investigation and optimization of the process, D can serve as an optimization criterion. One must only keep in mind the restriction that the distribution of D is doubly bounded (at 0.00 and 1.00), requiring mathematical methods appropriate to these restrictions. It is clear that if any di is zero, the associated D will also be zero. Further more, D is strongly weigthed by the smaller d's. On the other hand, D=1 i.e. unity, only when all d's are unity i.e. di = 1 (i=1,2,3, ...k.). Another important point is that equation $D = k\sqrt{d_1, d_2, \ldots d_k}$ makes it possible to describe d's and D in terms of the same desirability values e.g. d1 = d2 ... = dx=0.37 one has D = 0.37. The concept of D proved useful in developing the composition and quality of paper required by the customer. The following case study reveals, how the desirability concept can be used for addressing process variability & quality complaint in paper Industry.

CASE-MAT:- "Century's 58GSM Maplitho white paper"

The application of desirability function is being taken. Taking the example of Maplitho white paper manufactured on paper machine 1, we have the **ISO** quality specifications for maplitho white paper as:

GSM Manufactured : 58 gsm.

Avg. substance : ± 2 gsm

: 56<gsm.<60 for 58gsm.

Table 3.1 Control Chart Statistics.

Avg. Sub. g/m²	B.F.	B.L. Avg. meters	Tear Factor Avg.	Cobb 60	Ash %	Bulk	Brightness	Opacity
58.9	31	3390	53	20	7.0	1.20	85	84.2
59.3	33	3680	52	20	8.0	1.20	84.8	85.0
59.7	33	3390	52	19	8.0	1.17	85.2	85.4
57.9	33	3620	52	20	9.0	1.19	85.0	85.8
59.2	32	3560	50	21	6.0	1.18	84.2	84.6

Bulk (cm^3/gm)	: $1.15 \geq \text{Bulk} \geq 1.25$	$\frac{\text{(Caliper)}}{\text{grammage}}$
Burst factor	: 16 + Minimum	(y≥ymin)
Tear factor	: 45 + Minimum	(y≥ymin)
Breaking Length	: 2800 Minimum meters	(y>ymin)
Double Folds	: 6(Minimum Folds)	(y>ymin)
Ash %	: 8 %	
Brightness (%Ref.)	: 80% Minimum	(y>ymin)
Opacity (%)	: 82% Minimum	(y>ymin)
Cobb 60 (gm/m^2)	: 24 Minimum	(y<ymin)
Smoothness	: 40sec./50ml. Minimum	(y>ymin)
Porosity	: 10Sec./100ml. Minimum	(y>ymin)
Waxpick	: 8A clear	
Moisture %	: 4.5 < Moisture < 5.5	

The control chart statistics of Maplitho white 58 GSM is tabulated (Table 3.1) for nine (09) physical parameters of the paper:

DESIRABILITY ANALYSIS AND CALCULATIONS

The desirability function of each property is evaluated seperately. If the desirability of each functional parameter is denoted by d_1, d_2, d_3, d_4, d_5, d_6, d_7, respectively then the over all desirability is calculated by

$$D = \sqrt[7]{d_1 d_2 d_3 d_4 d_5 d_6 d_7}$$

or

$$D = (d_1, d_2, d_3, d_4, d_5, d_6, d_7)1/7$$

The individual desirability function for GSM's calculated as :-

Y_1 GSM : For the manufactured maplitho white papers in 58 gms.

$56 < Y_1 < 60$ according to the ISO specification. for any property with mid specifications the desirability is defined by :-

$$d = \exp [- (1\ Y'1^n)]$$

Where d is desirability, n is any number, not neccessarily an integer and $0<n<\infty$.

Also, $$Y' = \frac{2Y - (Ymax + Ymin)}{(Ymax - Ymin}$$

Chosing an optimum desirability d = 0.63 or 0.8 and y = 57.5 gms.

as some mid specification, the number 'n' can be calculated as:

$$n = \frac{\text{In In (1/d)}}{\text{In (1 y'1)}}$$

Now Y max = 60 & min = 56

Y' = (0.5y-29) from equation (IB)

$$n = \frac{\text{loge loge (1/8)}}{\text{loge}|(0.5y-29)|}$$

$$= \frac{\text{loge loge (1/.8)}}{\text{loge}|(0.5x57.5-29)|} = 1.0$$

We run eighteen trials for n = 1.0 and using equation $d = \exp. [- (1y'1)^n$ i.e.

$d_1 = \exp. [- (10.5y - 291)^{1.0}]$

For GSM (y = 58.3) $\Rightarrow d_1 = 0.86$ & so on... .

RESULTS AND DISCUSSION

Using the control chart statistics from table 3.1 the component desirabilites and mean component desirabilities were calculated & tabulated. Based on mean component desirabilities, the overall mean desirability (D) - values are calculated by taking the geometric mean of the component desirabilities (i.e $d_1 d_2 \ldots\ldots\ldots d_7$). The D - values directly reveal the psychological reactions of the customer to the paper (Table 4.0). The maximum D- values comes out to be 0.625 for the maplitho 58 gsm paper. Furthermore it was calculated that out of 18 trials, 10 trials have the D - values in the acceptable range (i.e. D> 0.5) & non - of the sample is on the borderline quality level. The following conclusions can be drawn, comparing the manufactured rating and the customer rating.

(i) The desirability analysis for GSM reveals that the occurrence of higher GSM desirabilities are sufficiently high. The desirability for GSM as a property is greater them 0.67 (mean d > 0.67). Thus the customer's complaint regarding GSM variation is not genuine. The product was "acceptable and excellent" as for as GSM is concerned. The same is true in the case of bulk property of the supplied paper. Though the bulk was found low as compared to the competitor's sample but was "acceptable

Table 4.0 The Over all Desirability

GSM d_1	Bulk d_2	Burst Factor d_3	Cobb 60 d_4	Brightness d_5	Opactiy d_6	Breaking Length d_7	Over all desirability D
0.86	1	0.420	0.200	0.550	0.200	0.200	0.398
0.52	1	0.530	0.285	0.467	0.422	0.680	0.516
0.42	0.95	0.470	0.376	0.630	0.532	0.200	0.465
0.95	0.98	0.370	0.467	0.550	0.630	0.550	0.608
0.54	0.96	0.422	0.553	0.200	0.308	0.461	0.445
0.40	0.95	0.530	0.376	0.200	0.337	0.384	0.440
0.40	0.98	0.200	0.630	0.285	0.558	0.399	0.440
1	0.98	0.630	0.553	0.200	0.422	0.415	0.531
0.60	0.95	0.780	0.697	0.330	0.506	0.423	0.580
0.78	0.98	0.750	0.755	0.376	0.365	0.200	0.531
0.47	1	0.713	0.630	0.400	0.394	0.214	0.547
0.36	0.98	0.365	0.553	0.422	0.674	0.207	0.457
0.47	0.96	0.370	0.467	0.592	0.558	0.636	0.555
0.79	0.96	0.422	0.467	0.630	-	0.642	0.625
0.84	0.98	0.308	0.902	7.4×10^{-4}	-	0.655	0.271
0.50	0.98	0.422	0.844	0.467	-	0.469	0.580
0.60	0.90	0.308	0.876	0.1613	-	0.312	0.495
0.45	0.92	0.308	0.972	0.8435	-	0.726	0.645

and excellent" as for as the ISO specification for bulk go.

(ii) The mean desirability in case of burst factor is 0.51 and is on the lower side. We can say that Burst of "maplitho 58 GSM" paper is "acceptable but poor". The burst factor can be improved and the shop floor is advised to keep burst at par with the **ISO** specifications.

(iii) The mean desirabilities for cobb, brightness and opacity are 0.59, 0.50 and 0.51 respectively. This implies that the product is reasonably acceptable so for as the cobb, brightness and opacity of the paper is concerned.

(iv) In case of Breaking length, the occurrence of high and low desirabilities are approximately same. The mean of the B. length desirability is 0.46 and is on lower side. The deviation from high values of breaking length and large sample occurrence renders the product in poor and acceptable range. It is advisable to keep the breaking length with-in the ISO specifications. Therefore a broad conclusion can be drawn that the maplitho white paper 58 GSM manufactured On paper machine I and supplied in April 99 was acceptable as for its physical characterization is concerned. The product send to the market was acceptable & good from the point of view of physical attributes. It was rated by the customer as "acceptable but poor" or at the borderline because of low burst and breaking length. Furthermore it was low in bulk as compared to the paper supplied by the competitor. The aggregate quality of this paper is "acceptable and good" in comparison with **ISO** standards.

This investigation provides a basic stand to the company **(i.e. M/S Century pulp & paper)** that it had furnished a reasonably good commercial quality of maplitho white 58 GSM paper to its valued customer. Further the company can assure its customer about improvement in the weak physical properties (i.e. burst and breaking length) to ascertain best commercial quality in the subsequent orders, for the greater satisfaction of the customer.

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ACKNOWLEDGEMENT

The authors take this opportunity to express their gratitude to Shri R.L. Lakhotia (Joint President - works) & Shri S.K. Maheshwari (V.P-manufacturing) of M/S Century Pulp & Paper, for their support & persuasion. With immense pleasure, the authors states & records their thanks to Ms. Amita Singh for her critical remarks & case compilation exercise.

To the departmental members of Century's W.P.P. (process) & customer service department and to Shri Naresh Chandra Ji - the authors express their deep obligations for their personal interest in this project.