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SENSITIVITY ANALYSIS BY ARTIFICIAL NEURAL NETWORK (ANN) OF VARIABLES THAT INFLUENCE THE DIAGONAL TWIST IN A PAPERBOARD INDUSTRIAL MACHINE[1]

ANÁLISE DE SENSIBILIDADE, POR MEIO DE REDE NEURAL ARTIFICIAL, DAS VARIÁVEIS QUE INFLUENCIAM O ENCANOAMENTO DIAGONAL EM UMA MÁQUINA DE PAPEL-CARTÃO

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ABSTRACT

The dimensional stability of the paper may change due to middle exchange moisture, releasing the latent stress acquired into the manufacturing process. One result of this tension release is the diagonal curl. This study aims to conduct a sensitivity analysis of the different input's variables of an industrial paper machine, along with some laboratory measurements, in order to identify the importance in production of paperboard quality control and relate to the property of the paper called twist. A survey was made of the production history, relating to 2012, to observe the products with the highest quality losses. From this, they were correlated with the critical points of measurement profile in the machine cross direction and consequently with the paper. It was found some changes once the variables correlated with twist, referring to the three analyzes of the profile (tender side, middle and drive side). It was revealed, from the sensitivity analysis, that the most important and sensitive variables, respectively for the tender side, middle and drive side, were total flow from the top layer, vapor pressure in the 6th group of drying cylinders and mass flow side of the bottom layer of the formation of paperboard.
Keywords: twist; sensitivity analysis; dimensional stability; paperboard.

RESUMO

A estabilidade dimensional do papel pode sofrer alterações devido à troca de umidade com o meio, liberando o estresse latente adquirido no processo de fabricação. Um dos resultados dessa liberação de tensões é o encanoamento diagonal. Este estudo tem por objetivo fazer uma análise de sensibilidade das diferentes variáveis de entrada de uma máquina industrial de papel, juntamente com algumas medições laboratoriais, com a propriedade do papel denominada de encanoamento diagonal. Foi feito um levantamento do histórico referente a 2012 para observar os produtos com as maiores perdas. A partir disso, correlacionados com os pontos críticos do perfil de medição na direção CD. Algumas alterações na ordem em que as variáveis correlacionavam com o *twist*, referentes nas três análises do perfil (lado comando, meio e acionamento). Foi revelado, a partir da análise de sensibilidade, que as variáveis mais importantes e sensíveis, respectivamente, para o lado comando, meio e acionamento da máquina, foram o fluxo total da caixa de entrada da camada cobertura, pressão de vapor no 6º grupo e fluxo de massa lateral da camada base (*Module Edge*).
Palavras-chave: encanoamento diagonal; análise de sensibilidade; estabilidade dimensional; papel-cartão.

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INTRODUCTION

Twist in paper is a recurring problem for the industry paperboard when the ultimate goal is to print on paper sold in sheets, cut according to the definition of the end customer (GOYAL, 2012). Sharp twist makes it impossible to use the batch at the time of supply of printers and thereby hindering the end use of the product and limiting production in the graphic that causes extensive damage to the process of commercialization and use of paperboard. The aggravating these problems occur due to repetitive stops to remove sheets trapped in the power system of institution graphic printers.

The dimensional stability is the susceptibility, of the paper, to changes in its dimensions when there are changes in its moisture content (GALLAY, 1973).

Twist is intrinsically linked to phenomena that govern the operation of the head box, fiber orientation resulting from sheet formation and stability of the paper after formation (NISKANEN; KAJANTO, 1998).

Figure 1 illustrates the paper deformation by distinguishing twist and curl.

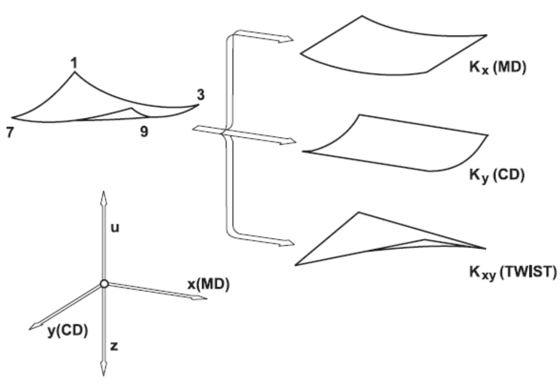

FIGURE 1: Out of plane deviation (LEVLIN et al., 1999).
FIGURA 1: Desvio fora do plano (LEVLIN et al., 1999).

Promoting stability of papers can lead to loss of properties. For example, the lower the degree of refining and higher the porosity, the paper is less compact and will have greater dimensional stability. Since the expansion of an individual fiber will have less influence on the adjacent fibers. A pronounced refining in fibers provides more hydration, resulting in decreased of stability (WATTY, 1987).

Sensitivity analysis is a step of creating artificial neural network (ANN), where identify the variables that are influencing the output model. Allowing to identify the parameters that cause the most disturbance in the performance of the model. Thus, the sensitivity analysis is performed in order to define the influence of some parameters (input) in the results (output) (JAKHRANI et al., 2013).

In this work, a survey was made about the data production and discussed the relationship between independent variables and twist (dependent variable), through sensitivity analysis. Thus, defining what the variables that most influence in the models to improve the control of production are, efficiency and quality of construction the paperboard produced industrially.

MATERIALS AND METHODS

Description and material selection

This study was conducted in a paperboard machine of Indústria Klabin de Papéis (KPMA) held in Monte Alegre, Paraná state, Brazil. Initially, within the range of products manufactured by KPMA a survey was done to observe the products with higher occurrence of downgrading based on twist paperboard property.

The paperboard measured is made up of three fibrous layers, the cover layer being composed by bleached pulp. Up these fiber layer are applied three coating layers and on the opposite side of the paper (bottom side) is applied a layer of starch, as shown in Figure 2.

The bottom layer is composed of long fibers, derived Kraft pulping. The middle layer is a mixture of chemi-thermomechanical pulping, short and long fibers from Kraft pulping. The top

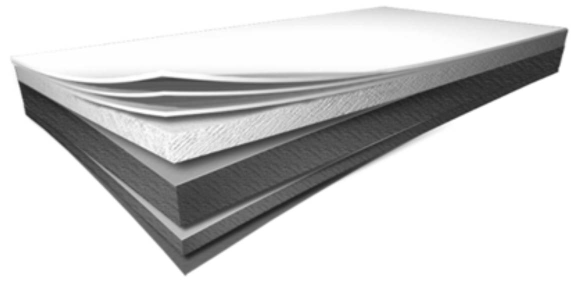

FIGURE 2: Structure of paperboard in z direction.
FIGURA 2: Estrutura do papel na direção z.

layer is composed of bleached fibers (proportion of 80% hardwood and 20% softwood).

Determination of twist

The twist analyses are made after each jumbo roll in the cross machine profile. The samples (30x25cm) are prepared following internal procedure of the quality control laboratory. The first measurement point represents the tender side (TS) of the machine and the rest of the measurements occurs every 40 cm, up to a total of 10 samples. The latter being indicated by the drive side (DS). The samples are air-conditioned for 20 minutes. The methodology is done in a acclimatized room, aiming at a temperature of 23 ± 2 °C and humidity of 50 ± 10%. Figure 3 shows the preparation.

Observing the numbering of the rectangle (30x25 cm) in the Figure 3, we can calculate the value of twist. The methodology is given by the difference between the highest value of one of the edges (1/3 or 2/4) at the lower value of the other edge.

Creating the data set

Initially, a survey was made of the production and selected the desired products: CHD, CHW and CKF. The abbreviations, CHD and CHW, represent Carrier Board (CB) products. On the other hand, the abbreviation CKF includes Folding Box Board (FBB).

Industrial production was analyzed from January to December 2012, through of data stored on the internal server of KPMA by way of Plant Information System. The data was collected from the end of each jumbo, the amount remains in about 2200 measurements.

Choice of variables

The criteria for choosing the variables to be correlated with the property occurred based on pertinent literature and along dialogues with machine operators at board machine 9 (BM9). The variables were correlated after removing outliers, according to daily reports indicating failure or deviations in the production process. A total of 62 variables were evaluated.

The tags, represented by a series of numbers and letters (eg. 392PT2064A) which store the information related to the description, function, finality, in short, the characteristics that describe the studied variable.

Sensitivity analysis (SA)

This analysis serves to evaluate the intensity of interaction (sensitivity) of each input variable to the output variable. Indicating, in decreasing order, the variables with the greatest impact.

The analysis is made by the sensitivity absolute average, average and peaks. Sensitivity absolute average is the sum of the average temporal distribution of the absolute values of partial derivatives of the input-output pairs.

$$\text{Absolute Average} = \frac{\sum_{k=1}^{N_{pats}} \left| \frac{\partial o_{k,i}}{\partial x_{k,j}} \right|}{N_{pats}} \quad (1)$$

Which is the number of patterns in the data set on which the distribution is calculated, $x_{k,j}$ is the input to the j^{th}, the pattern k^{th}, and $O_{k,i}$ is the i^{th} output for the k^{th} standard.

Sensitivity average is the average of the values of the partial derivatives (real, not absolute).

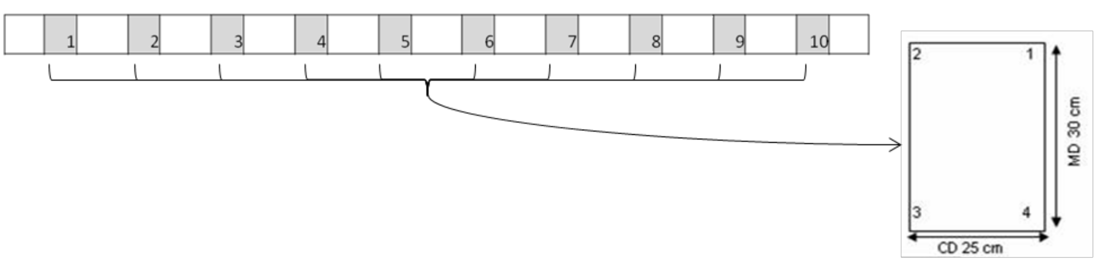

FIGURE 3: Test samples and laboratory measurement of twist.
FIGURA 3: Medição laboratorial de *twist*.

$$\text{Average} = \frac{\sum_{k=1}^{N_{pats}} \frac{\partial o_{k,i}}{\partial x_{k,j}}}{N_{pats}} \quad (2)$$

Peak sensitivity is the maximum of all partial interactions between inputs and output.

$$\text{Peak} = \text{máx}\left(\left|\frac{\partial o_{k,i}}{\partial x_{k,j}}\right|, k \in 1, 2, \ldots, N_{pats}\right) \quad (3)$$

The program used to process variables was the Property Predictor® software (PAVILION, 2011).

A sensitivity analysis was performed with the trained ANN. From the points at which the neural network was tested in the dataset are calculated, statistically, which were excited entry. In other words, led to further variability in the output (gain).

RESULTS AND DISCUSSION

Collection and material selection

Figure 4 shows the percentage of kind of boards subject to twist downgrading, produced on the machine chosen for the study.

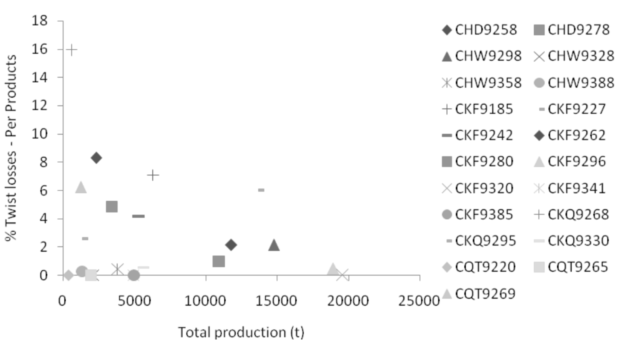

FIGURE 4: Distribution of card production (CB and FBB) in PM9.

FIGURA 4: Distribuição da produção de cartões (CB e FBB) na MP9.

The legend of Figure 4 shows that the letters correspond to the type of paper produced, the first digit indicates the paper machine where the product was made (eg PM9) and the last three digits express the nominal basic weight of the paper (eg : 227 g / m²).

Although the production of CKF9227 not is the most significant, corresponds to the largest exclusion. As exemplified and shown in Figure 5, the point values of laboratory measurements express great variability. Along with measurements exceeding the upper control limit (UCL), it was caused due to greater variation in their individual values that generated their respective averages.

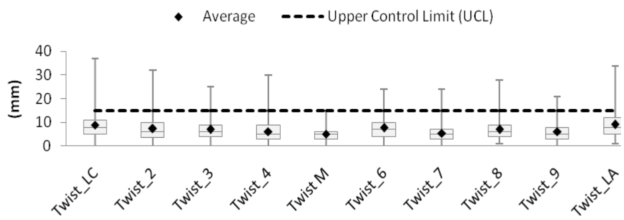

FIGURE 5: Measurement of laboratory samples, in mm, in the sectors sampled in the cross-machine direction for the CKF9227product.

FIGURA 5: Medição laboratorial, em mm, nos setores do sentido CD para o produto CKF9227.

According to (CARLSSON, 1981), papers with lower densities are more susceptible to deformed out of the plane, exacerbating the dimensional stability. In study, the largest disqualifications occur on the sides of the sheet due to the turbulence of the mass flow in the inbox. With this, the fibers show asymmetry along the cross-section and can be accentuated or softened by the jet/wire ratio, lip opening, machine speed, among others (LINDBLAD; FURST, 2001).

Based on Figure 5, the edges have been chosen the tender side (TS) and drive side (DS) because they present the greatest losses. And the middle of the machine, the specimens coded as position (5), for having submitted the lowest profile downgrading, opposite to the TS and DS.

Variables used in the sensitivity analysis to quantify the interaction between input and output

The analysis was performed using variables with potential impact on the studied property, as can be seen in Table 1. These variables include, in its entirety, the variations in both CD and MD direction of the machine. The variables arranged in the CD direction were mapped, transformed and applied in order to relate a segment with the final variable information. These values represent the averages in the range of the laboratory measurement of the twist valued in the samples, as shown in Figure 5.

TABLE 1: Input variables most influenced in twist.
TABELA 1: Variáveis para classificação, com influência no encanoamento diagonal.

Description	Tag	Unit
Twist TS	50_09_Twist_LC	mm
Twist M	50_09_Twist_M	mm
TwistDS	50_09_Twist_LA	mm
Curl 50% U.R. Pos.1	50_09_Encan50_1	mm
Curl 50% U.R. Pos.5	50_09_Encan50_5	mm
Curl 50% U.R. Pos.10	50_09_Encan50_10	mm
TSO Angle p01-02	50_09 506p01-02	°
TSO Angle p09-10	50_09 506p09-10	°
TSO Angle p19-20	50_09 506p19-20	°
TSI MD/CD p01-02	50_09 500p01-02 / 50_09 501p01-02	kNm/g
TSI MD/CD p09-10	50_09 500p09-10 / 50_09 501p09-10	kNm/g
TSI MD/CD p19-20	50_09 500p19-20 / 50_09 501p19-20	kNm/g
Fiber Orientation Angle_Bottom_049-070	39PERFANGULOFOBOTF4_049-070	°
Fiber Orientation Angle _ Bottom _265-286	39PERFANGULOFOBOTF4_265-286	°
Fiber Orientation Angle _ Bottom _535-556	39PERFANGULOFOBOTF4_535-556	°
Fiber Orientation Angle _Top_049-70	39PERFANGULOFOTOPF4_049-70	°
Fiber Orientation Angle _ Top _265-286	39PERFANGULOFOTOPF4_265-286	°
Fiber Orientation Angle _ Top _535-556	39PERFANGULOFOTOPF4_535-556	°
Fiber Ratio _ Bottom _049-70	39PERFORIENTFOBOTF4_049-70	
Fiber Ratio _ Bottom _265-286	39PERFORIENTFOBOTF4_265-286	
Fiber Ratio _ Bottom _535-556	39PERFORIENTFOBOTF4_535-556	
Fiber Ratio _ Top _049-70	39PERFORIENTFOTOPF4_049-70	
Fiber Ratio _ Top _265-286	39PERFORIENTFOTOPF4_265-286	
Fiber Ratio _ Top _535-556	39PERFORIENTFOTOPF4_535-556	
Shopper RieglerBottom	50_09SR_TQB	°SR
Shopper RieglerTop	50_09SR_TQC	°SR
Shopper RieglerMiddle	50_09SR_TQM	°SR
Performance PM9	39_Performance	
Velocity Pope	392M3820_D115_VEL	m/min
Grammage	9GRM_cond_ROLO_F1	g/m²
Coating grammage	39_Tinta_Total_Medido	g/m²
Thickness	9ESP_ROLO_F1	µm
Moisture	9UMID_ROLO_F1	% a.s.
% Softwood Refined Middle	392PCT_PB_MV	%
Breu Bottom	392FIC3001_CONS_ESP_BASE	kg/ton
Breu Middle	392FIC3002_CONS_ESP_MEIO	kg/ton
Breu Top	392FIC3003_CONS_ESP_COB	kg/ton
AKD Bottom	392FIC3014_CONS_ESP_BASE	kg/ton
AKD Middle	392FIC3013_CONS_ESP_MEIO	kg/ton
AKD Top	392FIC3029_CONS_ESP_COB	kg/ton

Continua...

TABLE 1 : Continued...
TABELA 1: Continuação...

Description	Tag	Unit
Slice Opening Bottom	392ZT2195A_AO01	mm
Slice Distance Bottom	392ZT2195B_AO01	mm
Pressure Headbox Bottom TS	392PT2194A	kPa
Pressure Headbox Bottom DS	392PT2194B	kPa
Total Flow Headbox Bottom	391_FLUXOTOTAL_CALC_CX_ ENTRADA_LB	l/min
J/W Bottom	392VJ_VT_BASE	
Slice Opening Middle	392ZT2063A_AO01	mm
Slice Distance Middle	392ZT2063B_AO01	mm
Pressure Headbox Middle TS	392PT2064A	kPa
Pressure Headbox Middle DS	392PT2064B	Kpa
Total Flow Headbox Middle	391_FLUXOTOTAL_CALC_CX_ ENTRADA_LM	l/min
J/W Meio	392VJVT_MEIO	
Slice Opening Top	392ZT2061A_AO01	mm
Slice Distance Top	392ZT2061B_AO01	mm
Pressure Headbox Top TS	392PT2062A	kPa
Pressure Headbox Top DS	392PT2062B	kPa
Total Flow Headbox Top	391_FLUXOTOTAL_CALC_CX_ ENTRADA_LC	l/min
J/W Top	392VJ_VT_COB	
Module Edge TS Bottom	392FT2141A	l/min
Module Edge DS Bottom	392FT2141B	l/min
Pressure transmitter TS smoothing press	392PT5546A	kNm
Counter press	392PT5546B	kNm
Pressure transmitter DS smoothing press	392PT5546C	kNm
Cooked Starch Concentration	MP9_T_AMIDO_COZ_CONC	%
Steam Group 6 ° Lower	392PIC4046_MV	bar
Pressure Differential 6th Group Bottom	392PDIC4047_MV	bar
Steam Group 6 ° Upper	392PIC4048_MV	bar
Pressure Differential 6th Group Top	392PDIC4049_MV	bar
BIAS 6º Group	392BIAS_GRUPO6	

Sensitivity Analysis (SA) of the machine variables

The values of sensitivity analysis, values obtained from ANN, represent only the amount of data selected in the period described above. A sensitivity analysis was used to obtain a better understanding of the dataset in an attempt to analyze the variables and outliers that may have been generated by misreading the time of collection.

The machine variables that have any influence on twist paperboard in the tender side (TS), the drive side (DS) and the middle sheet (M) in the cross direction (CD) of the machine are shown in Figure 6, Figure 7 and Figure 8.

The most significant variables influencing the twist are observed in the range of mean absolute from the highest values to the lowest ones. Therefore, the most important variables are those that have higher average absolute value. The set of 62 variables are shown in Table 1, listed only the fraction consistent with the relevant to the discussion. They are presented in three figures following the portions related to TS, M and DS. These figures can be seen, in order, from the highest to the lowest values, the degree of significance of their participation in the effect of twist and can then be worked in order to provide better control of cupping diagonal cardboard.

From the 19 selected variables, as exemplified in Figure 6, Figure 7 and Figure 8, some of them have the same degree of importance, because they had the same absolute average.

The distance or retraction of the lip has an influence on way as the mass flow reaches the forming board. For lip retracted head box, the tendency of the mass is to attain on the forming board with greater pressure. Lip advance, the formation of the web will be defined by the speed of the mass when it reaches the forming board (MACDONALD; FRANKLIN, 1970). The speed can be controlled by the internal pressure of the head box and the lip opening.

Twist is always related to the orientation of the fibers. This orientation combined with changing moisture causes a change of the diagonal cupping. But it cannot be caused by moisture flow on one side of the paper as it would be for MD curl or CD curl. The root cause is always the structure of the paper. Changes in humidity can only aggravate the phenomenon (NISKANEN; KAJANTO, 1998). Chen and Berggren (2009), points out that the fiber orientation is the property sheet that determines the strength and dimensional stability (strongly associated with curl and twist).

The speed difference between the jet and wire affects directly the profile of TSO. Thus, the orientation between the bottom and top layers may change and result directly in twist (LINDBLAD; FURST, 2001).

Twist represents the combination of curvature (curl) in CD and MD, higher deviations aggravate the problems of twist. Caused by deviations in from machine direction (VOITH, 2012).

Based on the sensitivity analysis of the variables, the top 5 ones that impact in twist were selected, according to the dataset, and are presented in the table below:

In Table 2, we can observe, in descending order of importance, in other words, that the variables listed at the top of the table had greater influence on the twist. However, it was shown no unanimity in their analysis. It would be expected some correlation between TS and DS fractions, as both represent major losses along the profile.

Furthermore, it was expected to observe variables related to fiber orientation, J/W ratio, opening and retraction of the lip among the most strongly influenced the amounts of twist. Variables inherent in the dynamics of the head box, such as pressure, retraction, flow, lateral flow

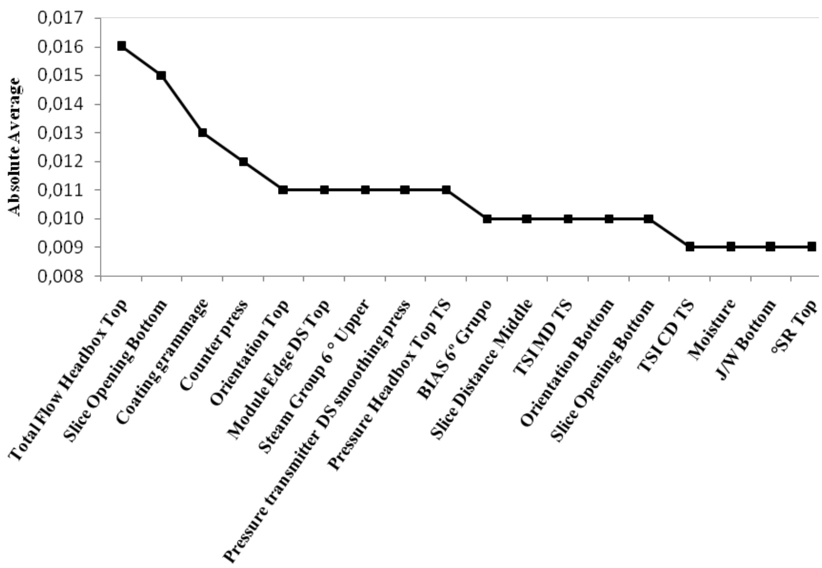

FIGURE 6: Sensitivity Analysis (AS) for the tender side of the machine.
FIGURA 6: Análise de Sensibilidade (AS) para o lado do comando da máquina.

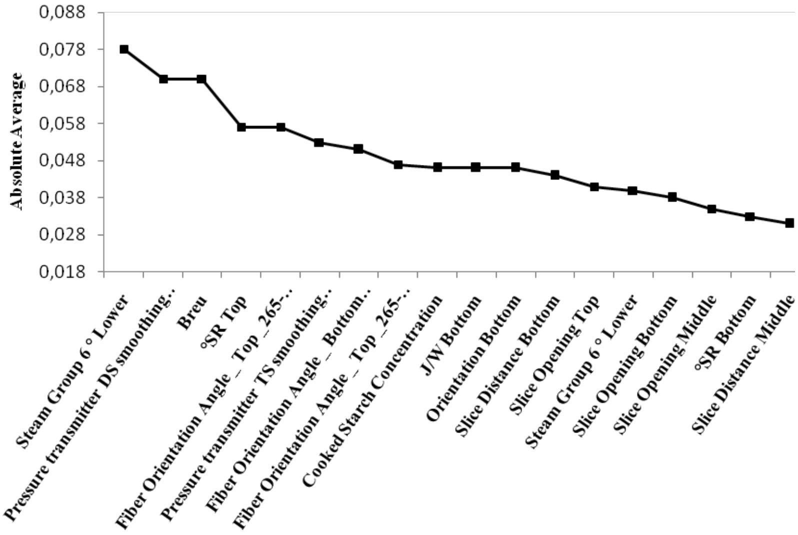

FIGURE 7: Sensitivity Analysis (SA) to the middle position of the sheet in the machine direction CD.
FIGURA 7: Análise de Sensibilidade (AS) para o meio da máquina.

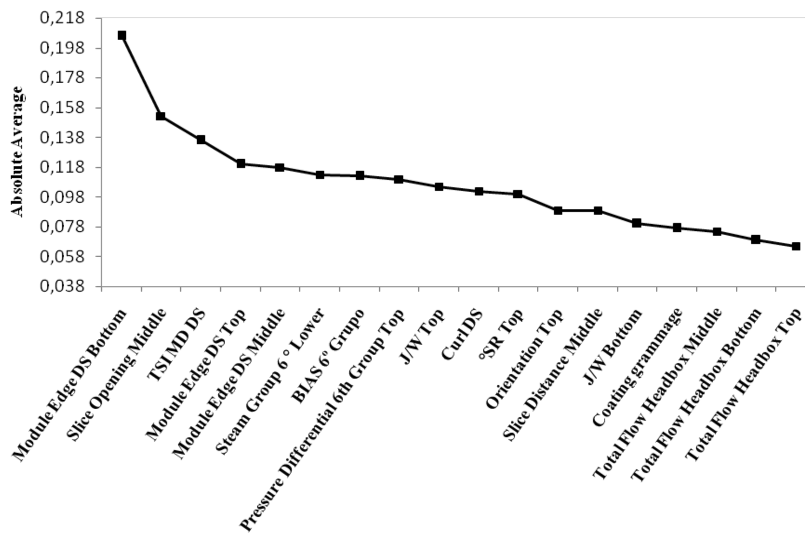

FIGURE 8: Sensitivity Analysis (AS) for the drive side of the machine.
FIGURA 8: Análise de Sensibilidade (AS) para o lado de acionamento da máquina.

(Edge Module) have direct influence on the fiber orientation. Being further inputs to calculations J/W.

A tool used, for the operation, to correct the twist profile is the adjustment in dry section, showing up with greater intensity in the middle machine. Such correction should not be applied to correct the twist, being correlated with the profile of curl (VOITH, 2012). This type of control transmits a false control over the property in question, because as you change the moisture content of the atmosphere, it releases tension action to reveal the real dimensional instability of paper.

The information contained in the Sensitivity Analyses show the importance of conducting the analysis for the improvement of neural networks, as this information enables the development of more robust models, with fewer outliers and more accurate in predicting the property in question.

TABLE 2: Variables for classification, in order of importance, to act as control on twist behavior.
TABELA 2: Variáveis para classificação, em ordem de importância, para utilização no controle do encanoamento diagonal.

		TS	M	DS
Importance order of output variable	11°	Total Flow Headbox Top	Steam Group 6 ° Lower	Module Edge DS Bottom
	22°	Slice Opening Bottom	Pressure transmitter DS smoothing press	Slice Opening Middle
	33°	Coating grammage	Breu	TSI MD DS
	44°	Counter press	°SR Top	Module Edge DS Top
	55°	Orientation Top	Fiber Orientation Angle _ Top _265-286	Module Edge DS Middle

Where in: TS: Tender side of machine; M: middle of machine; DS: drive side of machine.

CONCLUSIONS

For the database analyzed the following conclusions can be established:

The data reveal a potential for the operation of the paper machine, in taking effective decision when corrections for losses due to twist.

An indication for production would better utilize the tools of operation of the paper machine. Changes in J/W carry much influence on fiber orientation, and are not being used with the appropriate frequency.

Demystify the relationship between correction twist profile acting on the dry section, protecting this device due to the performance in curl.

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