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Analysis of the Behavior of Mottling in Coated Board using Neural Networks

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Abstract**—** *Quality monitoring of paperboard depends on the measurement of several properties. Part of these properties have online devices to do measurements while another part can only be measured in the laboratory, an activity that sometimes require more time than a production of one entire jumbo roll or generate waste until fix the production.*

The advantage to use mathematical modeling as the neural networks is the ability to 'predict' online the product final properties through the machine's information such as speed, flow of pulp, coating weight and the quality of fiber as degree of refining and whiteness.

One of the properties used for assessing the quality of paperboard is the mottling that describes a marbled appearance on the paperboard surface. Mottling is determined using the method STFI™ Mottling who is characterized by a coefficient of variation of reflectance or standard deviation - defined by the methodology of the equipment. This property when out of parameters affects the quality of the final printed package, giving unsightly appearance.

The focus of this study is to determine parameters by mathematical modeling that influence the mottling in order to provide conditions for machine's operators to perform the process, reducing the variation of this property and keep the values inside the specified limits. The model was developed from historical data of 6 months of paperboard machine operation.

The results indicated that mottling is mainly influenced by the temperature of the dryer after coating process.

Application—Statement*: A further understanding of the mechanisms that cause mottling would help to optimize the paperboard quality.*

Keywords— Neural Networks, mottling.

I. INTRODUCTION

Mottling is a property of paperboard characterized by blotches on the surface and nonuniform appearance of the printed product [1]. The print mottle is a phenomenon where paper unevenly absorbs the solvent of the printing ink [10] characterized by a non-uniform drainage of ink into the paper or non-uniform paper absorbency [20].

Among the important aspects characterizing the paperboard, mottling is shown as a property that should be monitored very carefully during production and can be defined as undesired variations in color density of board. [6] It could be influenced by base paper. Bad formation of the base paper can cause uneven binder distribution in a coating layer, which could mean uneven mottled print image [7]. Uneven formation and then variations in coat weight are usually behind this phenomenon If different areas of coating consolidate at different parts of the drying section under different drying rates, it makes structure of coating heterogenic, which then makes the printed image mottled[10]. Mottling also depends on factors such as surface properties, pore size and size distribution of the pigment [8].

Fahlcrantz and Johansson [9] suggest that three aspects of monochrome print mottling should be considered when evaluating a measuring instrument of mottling: the amplitude of variation, dispersion and reflectance level of printing.

The formation and uniformity of absorption of the baseboard are main factors causing mottling. The coating, formulated mainly of mineral pigments and binders, sets up the printing ink and it is sensitive to mottling, since the size and shape of the pigment and the binder mobility are factors that affect the structure of the coating and consequently the sensitivity of printing ink mottling. Variations of the weight of the coating or surface of the baseboard are indicative of occurrence of mottling [10].

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In practice, mottling is measured in the laboratory with samples taken at the end of the winding jumbo reel. This type of control assumes that results obtained represent the entire roll and changes are made with a delay from the end time of winding, up to publishing the results on quality reports.

A mathematical modeling tool for non-linear processes was used to estimate results of product quality and reduce the effects of late corrections due to laboratory analysis and avoid corrections made to jumbo roll data points.

In industries advanced control techniques like computation mathematical modeling are used to correlate the process parameters with the final product quality [2].

Paperboard Properties

Paperboard properties can be associated with fiber characteristics, quality of raw materials, and structure of paper machine and with machine operation, manipulated by operators [3]. Coating improves the printing properties of the paperboard [4]. The coat step is influenced by process application as drying, to consolidate the coating microstructure within the paperboard pores [5].

Effect of paper formation

The forming section consists of a head box and wire section. The head box dispenses pulp evenly onto the wire for the entire width of the machine. The most common wire section types are the fourdrinier, hybrid former and gap former. The wire section is where the water from the forming web is removed by drainage. The paperboard mentioned in this paper is produced in a fourdrinier wire section.

The term forming describes the dilution in the short circulation of the stock flow to a mix flow, the approach flow system, the cross machine direction distribution and jet generation of the mix by the headbox, as well as the creation of a wet web bydewatering of the mix in the wire section [4].

Mottling can be formed by an irregular formation of the base paperboard or uneven coating binder migration through the base paperboard during drying and coating consolidation. In **Figure 1,** arrows indicate the difference in coating thickness, resulting an uneven thickness of the base paper.

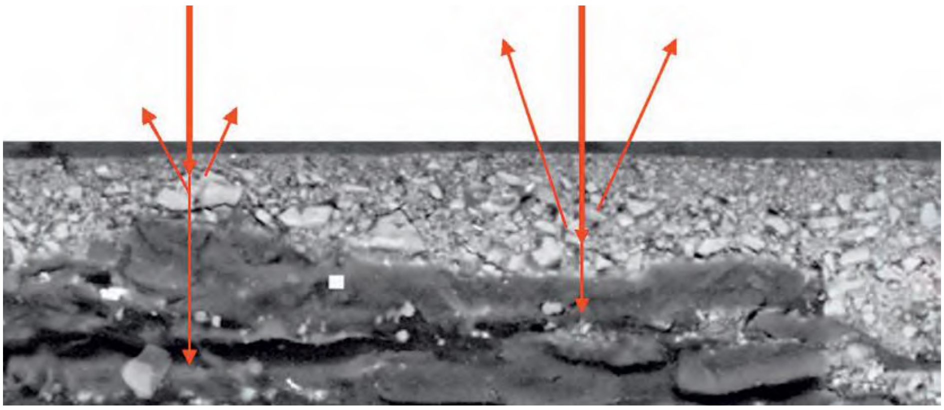

Fig.1: Cross Section of Paper

The arrows indicate the difference in film thickness due the irregularities in the thickness of the base paper.

SOURCE: "Mottling – Mottled impression."[21]

Besides wood fibers, paper consists of mineral and chemical additives. In the formation process these constituents are distributed stochastically. The formation of the paper is through distribution of these particles. Thus formation can be defined by the variability, in small scale, of the grammage of the paper.

The formation of the paper can be measured using different methods. These meters can give wrong results in the sense that the visual appearance is not equivalent to the structural uniformity of the paper because this property depends on the production process of the machine, coatingand calenderprocess. All these process can change drastically the optical behavior of the paper [11]. These changes occur, for example, due variations of fiber and coating distribution and thermal deforming on calender.

Effects of fines

Lu and Kuhn [12]evaluated the effects of fines and the formation of mechanical pulp papers in print mottling. The increase in drainage time deteriorates the formation of the paper and increases the weight of flocks. On other side, the increase in fines content improves surface properties, reducing roughness and porosity of the paper [12].

Effects of coating layers and dry process

Uniformity of coating layer is affected by the surface properties of base paper, such as roughness and porosity and also by penetration of coating in paper [13].

For the drying process of the coating there are three methods generally used: infrared, hot air drying and hot drying cylinders, which is also usually the order in which the coatings is dried. Right after the initial drying starts the consolidation phase that take place at the solids of the coating between 73% and 85%. Viscosity of the coating increases so much that pigment particles stop moving. The final pore structure of the coating is developed.

If coated areas are consolidated in dryer zones under different rates of evaporation it will generate heterogeneous coating structure and mottled appearance [10].Delaying to start evaporation result in drawing more water into the base paper [15].

The pore structure of the coated paper has been considered the most important concept of ink setting. The non-uniformity in pore structure is not necessarily caused by non-uniform distribution of the coating, in some cases the drying conditions are the source of the issue [14].

Through a pilot coater under different drying conditions and printing with six colors,Kim *et al.* identified a good way to reduce mottling. The results show how sensitivity is the drying conditions near to the first critical concentration zone influences the mottling [15].

The mobility of the particles in the coating layer is determined by the concentration of particles in the coating. Through simulation, it is confirmed that the surface smoothness of the coating is maximized when the surface roughness of the substrate is minimized and the solids content of the coating is maximized. The loss of particles from coating to substrate is undesirable and may cause reduction ofsoftness and strength due to migration of the binders and low coverage[5].

Effects on paperboard and print quality

The occurrence of print mottling in coated paperboard is one of the most difficult problems to fix in the offset printing [16]. Mottling is often the main determinant of the quality of print[15].

Nowadays it is known that the setting of the ink on coated paper is made by the evaporation of the ink vehicle (solvent) and penetration of ink. However, the micro porosity and surface chemistry of the coating are factors to control it [14].

The uneven distribution of weight coating on the surface of paper is one of the main factors of instability between the transfers of ink to paper because the immobilization occurs mainly by ink oil absorption by micropores structure and by the permeability of the coating structure [17].

Description of the paperboard

The paperboard, **Figure 2**, consists in three fibrous layers when the top layer is bleached and coated by three coating layers. On the opposite side (base board) is applied a layer of surface starch.

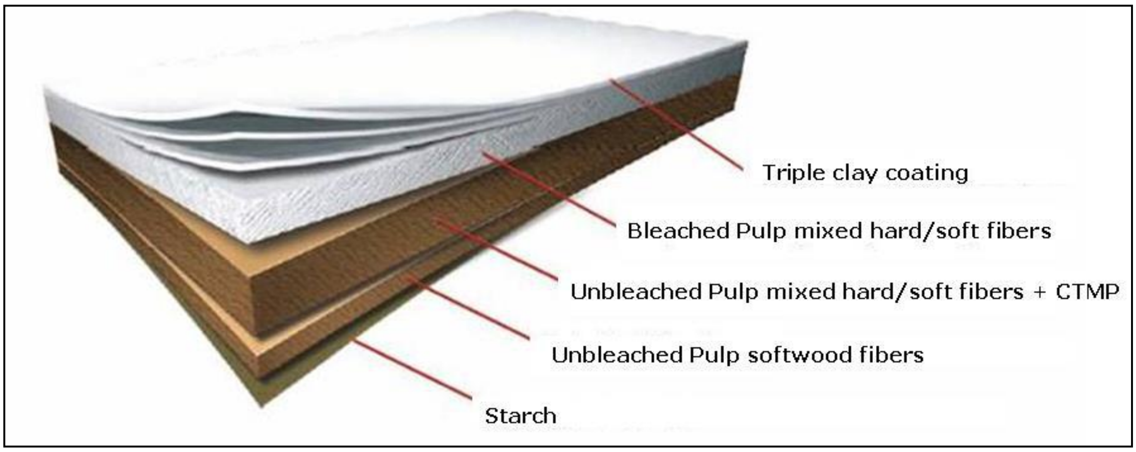

Fig.2: Paperboard Structure (SOURCE: COMPANY INFORMATION)

The lab analysis are made on samples taken from the end the winding machine. On Paperboard machine, this period occurs every 45 to 60 minutes, depending on the characteristics of the paperboard.

Mathematical modeling in a paper machine process

The control the paper machine quality parameters can be achieved basically in two ways: indirect control and model-based controls. The indirect controls are based on lab analysis of paper samples collected at the end of each jumbo roll. These samples are small portions compared to the full roll and it is assumed that the analysis results represent the entire roll. When changes occur in regulatory control, the manipulated variables become tools to control the quality parameters. This is usually determined by the operator knowledge and hypothesis consideration. The model-based controls (mathematical models)use the basic principles and statistical modeling [18]. Due to the complexity of the mathematical models to characterized mottling on this study it was decided to use a model using

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neural networks. The neural network is a parallel distributed processor made up of processing units, which are capable of storing experimental knowledge and make it available for use [19].The neural network is a structure that fits the data. This adaptation process is called training. After training, the relationships are established between input variables and output [3].

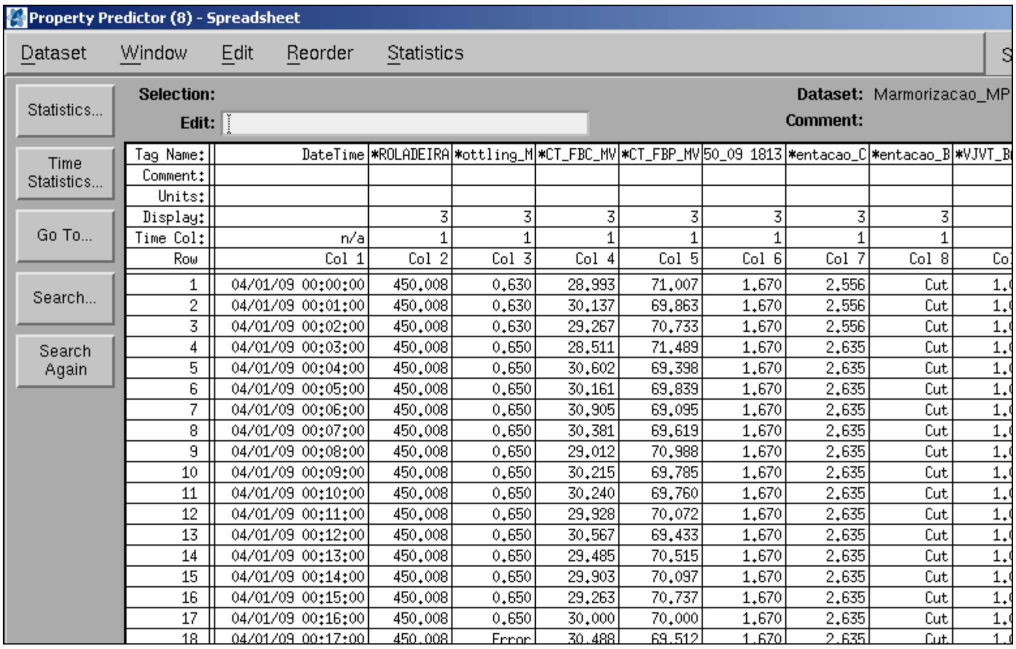
II. METHOD

The mottling model was developed from historical data from approximately 6 months of paperboard machine operation. These data included lab analysis of paperboard samples and process variables such as pulp flows, head boxes pressures, refining pulp degree, coating weight, drying temperature and others.

Neural Networks used in this work were built with the tool Property Predictor of Pavilion Technologies, are the MLP (Multi Layer Perceptron) with three layers, and back propagation algorithm.

Collect of historical data

To collect the data is important that it represent the entire operating range of the paper machine. Due to the complexity of information on paperboard machine, 75 variables were initially selected for the mathematical model, collected minute by minute, as showed on software datasheet Pavilion, **Figure 3**. These data are instantaneous values of the variables, without any filtering or averages.



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9	04/01/09 00:08:00	450.008	0.650	29.012	70.988	1.670	2.635	Cut	1.
10	04/01/09 00:09:00	450.008	0.650	30.215	69.785	1.670	2.635	Cut	1.
11	04/01/09 00:10:00	450.008	0.650	30.240	69.760	1.670	2.635	Cut	1.
12	04/01/09 00:11:00	450.008	0.650	29.928	70.072	1.670	2.635	Cut	1.
13	04/01/09 00:12:00	450.008	0.650	30.567	69.433	1.670	2.635	Cut	1.
14	04/01/09 00:13:00	450.008	0.650	29.485	70.515	1.670	2.635	Cut	1.
15	04/01/09 00:14:00	450.008	0.650	29.903	70.097	1.670	2.635	Cut	1.
16	04/01/09 00:15:00	450.008	0.650	29.263	70.737	1.670	2.635	Cut	1.
17	04/01/09 00:16:00	450.008	0.650	30.000	70.000	1.670	2.635	Cut	1.
18	04/01/09 00:17:00	450.008	Error	30.488	69.512	1.670	2.635	Cut	1.

Fig.3: *Datasheet of input variables*
Variables collected in the range of 1 in 1 minute.

Treatments were performed on input variables, based on operational range of these variables during stable production machine and removal of values considered erroneous by analyzing the data itself and range defined by the stable operation of the machine.

Structuring the model based on neural networks

It consists in portions of data separated for training and model test until the errors of training and testing are close. The training process of neural networks is performed when significant changes occur in the synapses of neurons. In this model were inserted26065 patterns, distributed in training, testing and validation according **Table I**:

Table.I: Distribution of patterns behavior of model

Total	Training	Test	Validation
26065	22636	2473	956
100 %	87 %	9 %	4 %

Despite the low percentage of tests for validation, real data are in the process minute by minute.

Analysis of the model

The model analysis must be done by examining the linear correlation coefficient (R^2) between the predicted value for the property and its true value, defined by equation 1.

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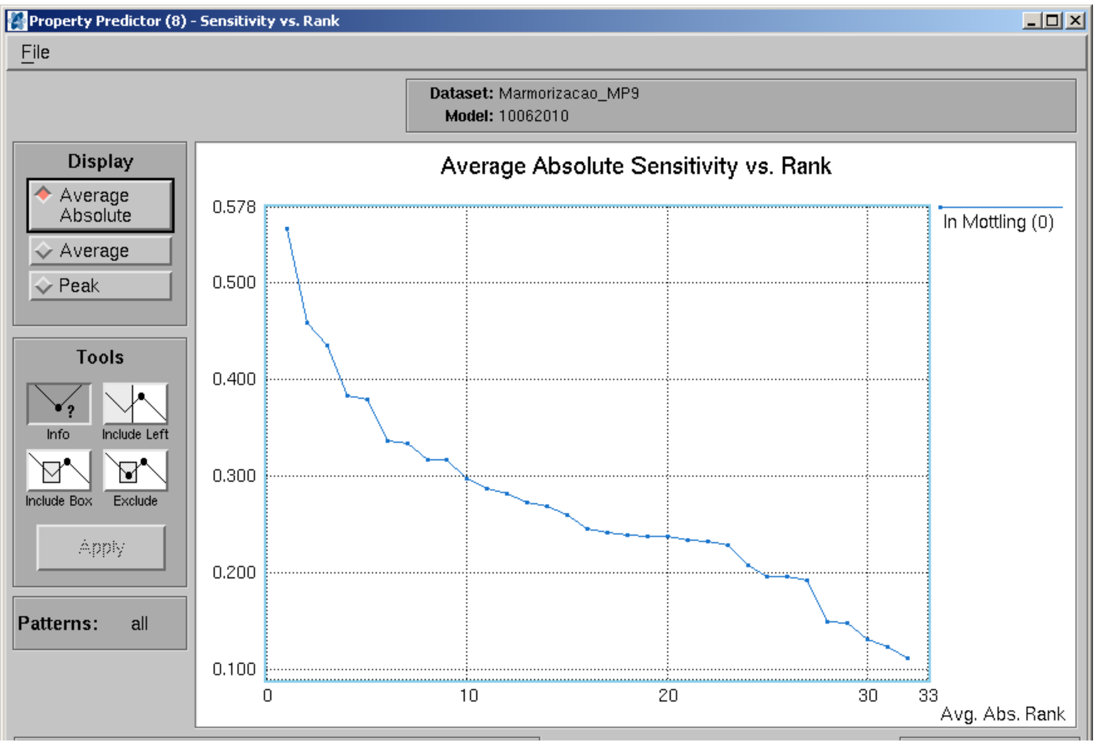
$$R^2 = \frac{\sum_{i=1}^{n}(x_{pi} - \bar{x}_p).(x_{mi} - \bar{x}_m)}{(n-1).S_p.S_m} \quad (1)$$

Where n is the number of values considered for the variable, x_p indicates the predicted value, x_m represents the measured value, x represents the average and Sp and S_m represent the standard deviations of predicted and measured values respectively. For a perfect model R² is equal to one.

Validation of the model

To ensure the model comprised the essential aspects of process, it was validated through the performance by unknown data by the mathematical model. **Graph 1** illustrates the sensitivity curve of the variables with the effect of mottling. This tool lets sort, in order of importance, the input variables used as classificationcriterion the average gain of curves of the model response.



Graph.1: Sensitivity Curve of variables in the mottling model

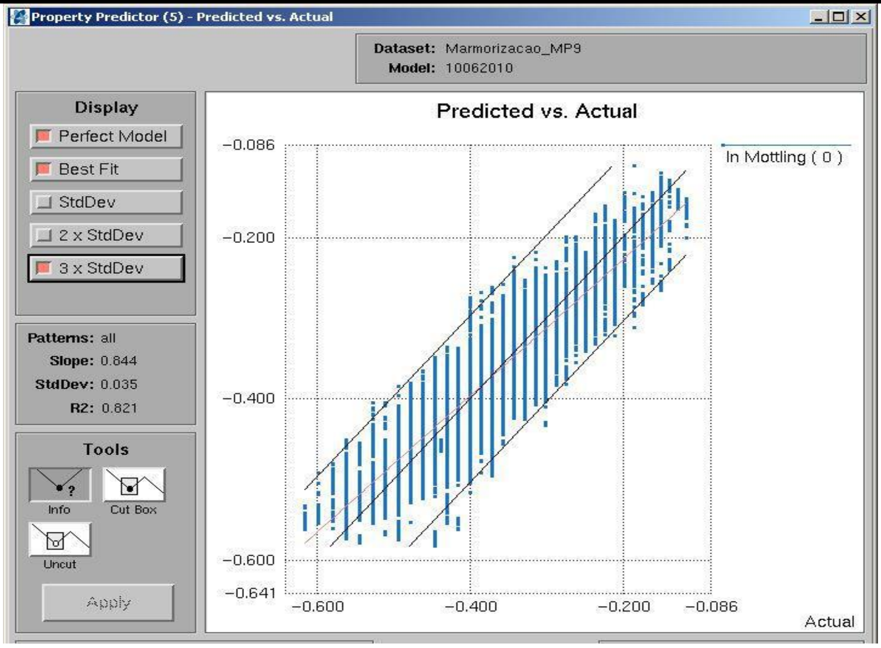
Defining of neural structure

The mathematical model for mottling on paperboard machine is a predictive network structure made up 32 input variables, 1 output variable and 14 neurons in the middle layer.

III. RESULTS

The linear correlation coefficient (R2) determined by the equation presented above was 0.821 demonstrating good correlation between the real value and the predicted one.

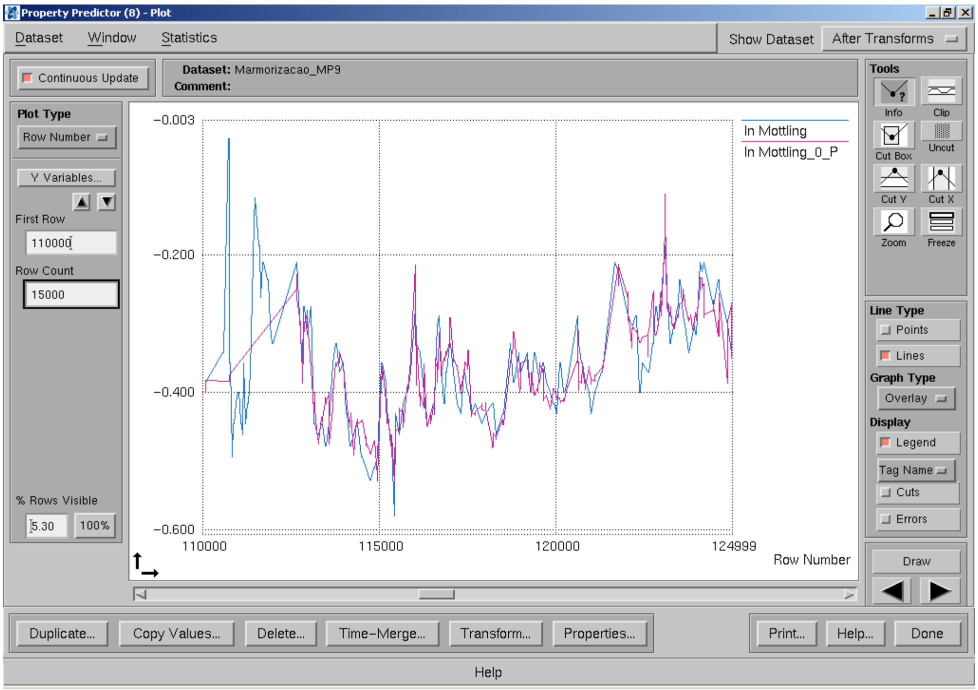
Graph 2 shows the curves with the results predicted and actual mottling.



Graph.2: Results of Predicted and actual mottling value.

With a variation of 3 standard deviation

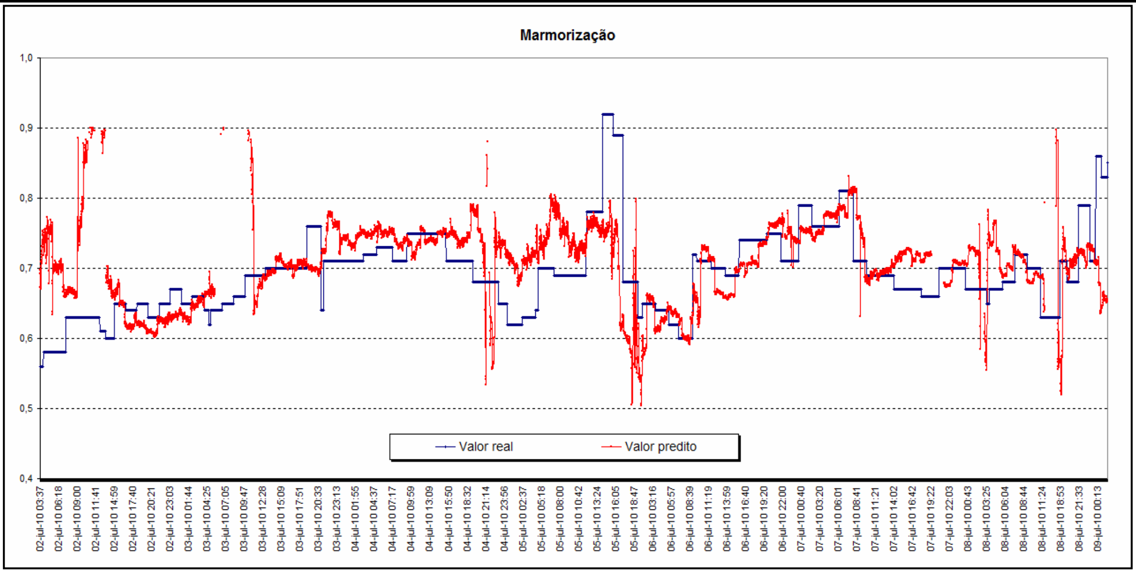
In **Graph 3** it is possible to see that the predicted values represent adequately the true values.



Graph.3: Comparison of predicted and true values

Predicted value represented by 'ln Mottling _0_P' line and real value represented by 'ln Mottling' line. The variation of the predicted value at the beginning of the graph indicates that one or more process variables instrument was out of action.

Graph 4 shows predicted results compared with laboratory results never seen by model in order to validate the model of mottling.



Graph.4: Comparison between mottling measured in the laboratory (Flat Line) and the mottling from the model (Rough Line)

Analyzing the results, it is possible to observe that the model could learn the behavior of mottling in the paperboard machine. Points out the trend are periods of instability on machine, start-up and calibration of measuring instruments.

APPLICATION STATEMENT

In terms of major input variables that influence the mottling property, it may be mentioned that these variables contribute as follows:

- Temperature of the coating dryers: The temperature control of hot air blown in the coating dryers affects the immobilization of coating. The right temperature provides a rapid consolidation of the coating avoiding the migration to the inside of the base board.
- The time using the same blades in coating applicators: The coating uniformly distributed over the board offers better uniformity of visual appearance, new blades helps to get it.
- Grammage: Increasing the grammage of fiber improves the outcome of mottling due its effect on the opacity of the board.
- Formation index board: Variations in formation on board highlight points of opacity and transparency of the board. Variations in formation in the middle and bottom layers provide transparent appearance of the board.
- Percentage of “ply bond” fiber in middle layer of the board: The ply bond fiber is characterized by a fiber with a high degree of refining. This fiber tends to be dark which does not favor mottling.
- Temperature of calender: The calendar works to uniform the base board before receive coating applications. It was understood that higher temperatures help to uniform the surface of the board.

IV. CONCLUSIONS

On this study was possible verify that mottling is strongly influenced by temperature of coating dryers (improving the coating immobilization) and by the time using the same blades, where new blades provide uniform distribution in the coating profile.

There is more than one factor responsible for the occurrence of mottling. Among these, there is the binder migration towards inside the baseboard, the irregular distribution of the coating on the board surface and the application and dryer of the coating. The structure of the base board is a highly relevant factor in the final result of this property.

The mathematical model developed for this work is a tool for the virtual sensor for mottling property.

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