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Prediction of Hot Glue Content for Sealing Toothpaste Carton

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Abstract

This research compared 2 types of model (regression model and artificial neural network) for prediction of glue content for sealing toothpaste carton from 4 sealing process factors, i.e., production line, diameter of toothpaste tube, pressure in glue nozzle during applying glue onto a toothpaste carton and glue temperature in a glue tank. Models under study included 3 regression models, i.e., multiple regression, polynomial regression and stepwise regression, and backpropagation neural network (BPN). The results indicated that the BPN model possessed higher prediction accuracy and generalization capability and lower bias. The best BPN model had a structure of 4-10-1 with the mean absolute error (MAE) of validating data set of 0.04 gram. In addition, the BPN model identified that the most influential sealing process factors affecting the prediction of glue content were pressure in glue nozzle and glue temperature in the glue tank. The packing department should concentrate on monitoring the value of both factors to control the consistency of glue usage.

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Keywords: Regression; backpropagation neural network, toothpaste carton, glue content prediction

1. Introduction

Toothpaste's manufacturers always concern about increasing their operation's efficiency along the supply chains due to a highly competitive market. Packaging and packages are known to be one of the key factors that affect the

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efficiency in the chain. Their functions are to contain, protect or preserve, communicate information, provide convenience in use, handling, transportation, storage, and distribution and promote the product. Toothpaste packaging system includes laminated tube, carton, leaflet inside the carton, fifth panels for promotion, bundle shrink film, bundle barcode, and shipping case. These packaging materials are assembled using an automatic machine. Since there are various sizes of toothpaste that require specific machine types and assembling speeds, these packaging materials must be designed to fit the capacity and limitation of the machine in each production line to smooth the flow of the production line. A critical activity contributing to flow's smoothness and considered as a tamper-evident is sealing the toothpaste carton with hot melt glue. Typically, size of the carton, machine in the production line, hot glue temperature and pressure in the glue nozzle during application of the hot glue onto a carton lid are known to influence the glue content on the lid and an effectiveness of the sealing process. However, the toothpaste manufacturer under study determines the glue content required and develops a glue requirement plan based on the size of the toothpaste only. As a result, the manufacturer faces the problem of underestimate the glue content and incurs high cost for urgent orders. These urgent orders were approximately 0.4 tons with costs of 13,000 USD monthly. This research examines the use of two predictive models to estimate the glue content from the sealing process factors for this manufacturer in order to reduce the costs of urgent orders. The predictive models of interest are regression model and backpropagation neural network model.

2. Predictive models

2.1. Regression model

Regression is widely used in modeling the input-output relationship. A general regression model for *m* input factors, $(x_1, x_2, \ldots, x_m) = \mathbf{x}$, can be expressed as:

$$Y_i = \sum_{j=1}^{1} \sum_{k=1}^{p} \beta_k Z_k(X_{ij}) + \varepsilon_i \qquad (1)$$

Where Y_i = response in the i^{th} trial, $Z_k(X_{ij})$ = power function in first order, second order or higher order and interaction terms, β_k= regression coefficient, and ε_i= error term from the i^{th} trial, and ε_i= error term from the i^{th} trial.

Regression models are very straightforward to implement, however, they require restrictive assumptions on the error terms such as normal random errors, constant error variance, and the absence of multicollinearity. In addition, their performance depends on the appropriateness of the functional forms (Madu, 1996).

2.2. Backpropagation neural network model

Backpropagation is one of artificial neural network (ANN) paradigms. ANN develops a mapping from the input variables to the output variables through an iterative learning process. The model consists of a large number of simple and interconnected adaptive processing elements called neurons. Associated with each connection is a weight that represents the information being used to solve the problem. These weights are iteratively adjusted by a learning process to optimal values that produce best fit of the predicted outputs over the entire learning data set. An ANN is generally organized into a sequence of layers: the input, hidden, and output layers. The input and output layers contain neurons that correspond to input and output variables, respectively. Data flow between layers across weighted connection. Each neuron in the hidden or the output layer sums its input signals from the previous layer weighted by the connection weights, and applies an activation function to determine its output signal. A multi-layer ANN with nonlinear transfer functions such as sigmoid and hyperbolic tangent can theoretically model any relationship to an arbitrary accuracy and is thus called a universal approximator (Hornik et al., 1989; Funayashi, 1989). Backpropagation network (BPN) is a feedforward multi-layer neural network trained by gradient descent method (Rumelhart et al.,1986). The training algorithm is based on minimization of total squared error of output