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Material Requirement Planning of MISO Production Process Using Transfer Function: A Case Study of Soap Production

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Abstract

In this study, transfer function is used to model the relationship between the input and output of a soap plant in order to do material requirement planning for the facility. It involved taking the inputs and outputs to the soap plant for three different years and determining the transfer functions. The determined transfer functions were compared with an equivalent model obtained using regression analysis. The resultsshow that transfer function models performed better than regression analysis. In addition the raw materials quality variability and product variability, a key characteristics of the process industry, was effectively modeled. Transfer function is therefore recommended as the preferred tool for material requirement planning for soap plants.

Keywords: Transfer function; Multi Input Single Output Process; Material Requirement Planning; Modelling;Soap production

Nomenclature, Symbols and Notations

k = lag variable
β_t= pretreated output series
α_t= prewhitened input series
v(B) = Transfer function
B = backshift operator
Y_t = process output at time t
X_t = process input at time t
y_t = differenced output series
x_t = differenced input series
$\hat{Y}_t$ = output forecast
$\hat{X}_t$ = input forecast
a_t = error term/white noise
υ_k = impulse response weight at lag k
h=ACF/PACF lag
q=order of moving average operator
p=order of autoregressive operator
d= number of differencing
θ = autoregressive operator
φ = autoregressive operator
H = Frequency response
χ = covariance function
b = transfer function lag
ω = difference equation variable for input
δ = difference equation variable for output
r = order of the output series
s = order of the input series
S = sample standard deviation
σ = population standard deviation
ρ = auto correlation function
γ = cross covariance function
μ=mean
ACF=Auto Correlation Function
PACF= Partial Auto Correlation Function
p = Frequency response between input and output

1.0 Introduction

Quite regularly in production systems, it is often necessary to predict/forecast the output of a process from a given input or determine the inputs required to produce a given quantity of output. This is very desirable in production planning and control

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systems. In material requirement planning, when the quantity of a given product to be produced in a given period, i.e. weekly, biweekly, monthly etc as the case may be, is determined from sales forecast and demand, it is often necessary to determine the quantity of raw materials that would meet the aggregate production plan. In the manufacture of discrete items, this is often done by product explosion. In the process industry, product explosion is not possible because of the nature of the production process. Therefore, an approximate way to relate the quantity of raw materials required to produce a given product is to model the relationship between the input to a process and the output of the process.

As noted in the literature, determining the relationship between the input and output of a production process is quite complex because the input to a production process is stochastic and the output is equally stochastic [1-5]. The complexity becomes even more in the case of multi-input single-output production processes as shown in Figure 1 in the case of a soap plant.

Figure 1: Schematic of the input-output relationship of a soap production system

Mathematically modelling the relationship between input and output of processes is usually done through transfer function modeling, regression analysis and its derivatives which includelinear system model, Koyck-lags model, Almon-lags model etc[4, 6, 7]. Of all these mathematical modeling tools named, many authors have praised the elegance, accuracy and superiority of transfer functions in modeling the causal relationship between input and output of a process over regression analysis and its derivatives[1, 2, 6, 7, 8]. Hence, our choice to investigate transfer function modeling as a tool for Material Requirement Planning (MRP) in a soap plant is based on sound scientific evidence backed by literature.

MRP as an operations management tool has evolved over the years. The earliest writing on the basic MRP calculations was due to Alfred Sloan who wrote about its use as far back as 1921 in his account of his years at General Motors [9].In the literature, it is noted that application of MRP in process industries is quite difficult and less straightforward when compared to industries that manufacture discrete items [10-15]. One of the complexities of application of MRP to process industries is that unlike in the manufacture of discrete items, the raw materials vary for the same quantity of product and the qualityof raw materials or end products could also vary considerably [10]. This apparent complexity makes transfer function an appropriate tool for modeling the complex relationship between the input and output of a process. By doing this we would have a more accurate recipe, an important component of the MRP in the process industry.

The aim of this research is to explore transfer function modeling as possible tool for MRP in the process industry with a soap plant as a case study; and also to compare the tool with regression analysis, a competing tool. The hub of our investigation is a local soap production company known as Promotex Industrial and Chemical Company Limited located at Umudim, Nnewi, Anambra State Nigeria. Promotex, a subsidiary of Chicason Group of Companies, was incorporated in 1984 for manufacturing and marketing of a wide variety of soaps ranging from toilet, medicated and laundry soaps.

2.0 Theoretical Brief

2.1 Multiple Input Transfer Function Models

In terms of the impulse response weights $v(B)$, the transfer function,$Y_t$can be represented as [7]:

$$Y_t = v(B)X_{t-b} + N_t \quad (1)$$

Recalling that $v(B) = \delta^{-1}(B)\omega(B)$ [7], we obtain:

$$Y_t = \delta^{-1}(B)\omega(B)X_{t-b} + N_t \quad (2)$$

Allowing for several inputs, $X_{1,t}$, $X_{2,t}$,…,$X_{m,t}$ we have:

$$Y_t = v_1(B)X_{1,t} + \cdots + v_m(B)X_{m,t} + N_t \quad (3)$$

$$Y_t = \delta^{-1}(B)\omega_1(B)X_{1,t-b} + \cdots + \delta^{-1}(B)\omega_m(B)X_{m,t-b} + N_t \quad (4)$$

Here $v_j(B)$ is the generating function of the impulse response weights relating to $X_{j,t}$ to the output. Assuming differencing is applied to the input and output series we obtain:

$$y_t = v_1(B)x_{1,t} + \cdots + v_m(B)x_{m,t} + n_t \quad (5)$$

Multiplying throughout by $X_{1,t-k}$, $X_{2,t-k}$,…,$X_{m,t-k}$in turn and taking expectations and forming the generating functions, we obtain:

$$\gamma^{x_1 y}(B) = v_1(B)\gamma^{x_1 x_1}(B) + v_2(B)\gamma^{x_1 x_2}(B) + \cdots + v_m(B)\gamma^{x_1 x_m}(B)$$
$$\gamma^{x_2 y}(B) = v_1(B)\gamma^{x_2 x_1}(B) + v_2(B)\gamma^{x_2 x_2}(B) + \cdots + v_m(B)\gamma^{x_2 x_m}(B) \vdots\vdots \quad (6)$$
$$\gamma^{x_m y}(B) = v_1(B)\gamma^{x_m x_1}(B) + v_2(B)\gamma^{x_m x_2}(B) + \cdots + v_m(B)\gamma^{x_m x_m}(B)$$

Substituting $B = e^{-i2\pi f}$, the spectral equations are obtained. For the case of m=2, the spectral equations are:

$$p_{x_1 y}(f) = H_1(f)p_{x_1 x_1}(f) + H_m(f)p_{x_1 x_2}(f) \quad (7)$$
$$p_{x_2 y}(f) = H_1(f)p_{x_2 x_1}(f) + H_m(f)p_{x_2 x_2}(f) \quad (8)$$

The frequency response functions $H_1(f) = v_1(e^{-i2\pi f}), H_2(f) = v_2(e^{-i2\pi f})$ can be calculated through methods outlined in the literature on spectral analysis [16, 17] etc. The impulse response weights can be obtained by the inverse transformation thus:

$$v_k = \int_{-\frac{1}{2}}^{\frac{1}{2}} v(e^{-i2\pi f})e^{i2\pi f}df \quad (9)$$

3.0 Methodology

The three year data obtained from Promotex was subjected to exploratory data analysis to detect outliers and patterns in the data. After the exploratory data analysis, the transfer function model according to Equation (4) was obtained using the input output data for the years 2011, 2012 and 2013.

In order to realize the transfer function model based on Equation (4), a plot of the 3-year input-output data was done using SPSS software. Following the plot, the data were investigated for stationarity, using the plots of the autocorrelation functions (ACF) and Partial autocorrelation functions (PACF). The inputs and output series derived from the plots were investigated for stationarity. Non stationary series were differenced to achieve stationarity. A univariate model was individually fitted to the input X1t and output Yt, and input X2t and output Yt for each of the years in order to respectively estimate prewhitened input series α_{1t} and α_{2t}, and pretreated output series β_{1t} and β_{2t} respectively. Calculation of the cross correlation functions, CCF (k) of $\beta_{1t}\alpha_{1t-k}$ and $\beta_{2t}\alpha_{2t-k}$ was used to identify r, s and b parameters of the transfer function model. Sequel to obtaining the nature of the transfer function models, the impulse response weights v_k, estimated with spectral analysis, were used to estimate the transfer function parameters in Equation (4).

4.0 Results

4.1 Transfer Function Modelling

Figure 2 shows the weekly raw materials consumption and the corresponding output (soap production) in the year 2011 for Promotex Nigeria Limited. The raw material X1 is soap chips while the raw material X2 is the additive.

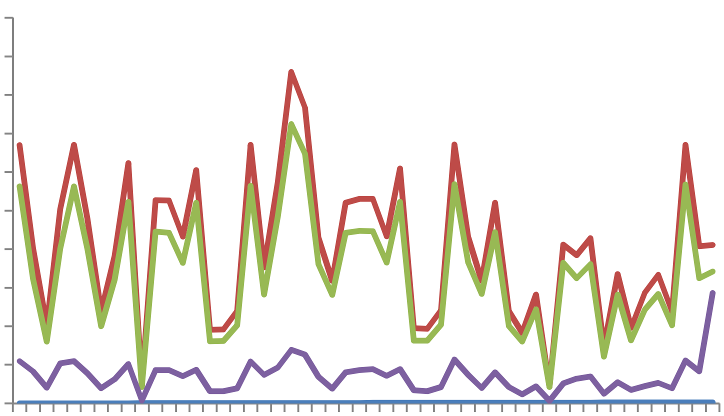

Figure 2: Weekly raw material consumption and output