Forecasting Analysis for Global Copper Clad Laminate Market

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Abstract

Demand forecasting is one of critical reference by top managers to make the strategy decision for future investment. The copper clad laminate (CCL) is the key material for print circuit board (PCB) and it can apply for consumer, computer, LCD, communication, automotive, aero space, medicine and defense application. The total global sale for PCB in 2008 is US$ 48.2 billion. In this research, we use grey model GM(1,1), rolling grey model (RGM) and Bass diffusion model to analysis global CCL market by six market segments – paper, composite, FR-4, FR-4 High Tg, FR-4 halogen free, Specialty between 2001-2008. The forecasting accuracy of global CCL market by six market segment was evaluated along with mean absolute percentage error (MAPE). In this study, Bass diffusion model MAPE outperforms the others two models GM(1,1) and RGM for this global CCL market forecasting analysis and is recommend for global CCL market forecasting analysis.

Keywords: Copper clad laminate, Print circuit board, GM(1,1), Rolling GM, Bass diffusion model

1. Introduction

Copper clad laminates (CCLs) are composite materials manufactured by pressing layers of filler material impregnated with resin together with layers of copper foil under heat and pressure. Laminates provide mechanical support for electronic components interconnect them electronically. The most common fillers materials used are paper and glass fiber. Paper has been used as reinforcement in a vast majority of printed circuit boards (PCBs). Paper Laminates are low priced and easily manufactured. Composite Epoxy Materials (CEM) is the group of composite materials typically made of woven glass fabric surfaces and non-woven glass core combined with epoxy resin. They are two major products – CEM-1 which is low cost, flame retardant, cellulose paper based laminate with only one layer of woven glass fabric and CEM-3 which is very similar to the most commonly used PCB material- FR4 but modified with white color and flame retardant. The most widely used and industry standard material for PCB process is FR-4 with Tg 135 degree C. The Tg of high performance FR-4 is 170 degree C and BT is 195 degree C, where Tg is glass transition temperature, a measure of temperature resistance.

The CCL is the key materials for print circuit board. The total global sale for PCB in 2008 were US$48.2 billion and the market share by geography are as follows. China/ 31.2%, Asia/21.1%, Japan /14%, USA/9.3%, Europe/6.7%. PCB is widely use for Consumers, Communication, Computer, LCD, Automotive, Aero Space, Medical and others electronic products. To align with different PCB applications, manufacturers need to use different raw materials – paper, composite, FR-4 high Tg, FR-4, high Tg, FR-4 Halogen Free and Special. All raw materials differences are based on different resin structure and end use application.

CCL forecasting is difficulty due to complex demand from different market. Prismark is a well known global consultant company that collects demand by six market segments and issues an annual report. They collect these data one by one (bottom up) then consolidate into completed data (see Table 1 for global CCL market demand by products segment from 2001-2008.)
Table 1. Global CCL market demand by products segment, Source: Prismark [1]

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>88.9</td>
<td>93.8</td>
<td>93.7</td>
<td>108.6</td>
<td>106.9</td>
<td>104.7</td>
<td>106.3</td>
<td>101.1</td>
</tr>
<tr>
<td>Composite</td>
<td>22</td>
<td>21.7</td>
<td>25.6</td>
<td>23.5</td>
<td>28.9</td>
<td>27.4</td>
<td>29.5</td>
<td>28.1</td>
</tr>
<tr>
<td>FR-4</td>
<td>129.8</td>
<td>131</td>
<td>130.7</td>
<td>140.3</td>
<td>171.2</td>
<td>195.4</td>
<td>210</td>
<td>206.6</td>
</tr>
<tr>
<td>FR-4 High Tg</td>
<td>20.5</td>
<td>22.5</td>
<td>28.2</td>
<td>36.4</td>
<td>44</td>
<td>51</td>
<td>53.5</td>
<td>55.2</td>
</tr>
<tr>
<td>FR-4 Halogen Free</td>
<td>0.3</td>
<td>0.9</td>
<td>3</td>
<td>6.6</td>
<td>9.8</td>
<td>11.4</td>
<td>20.9</td>
<td>26.4</td>
</tr>
<tr>
<td>Specialty(High Speed, Low Loss),BT and BT-</td>
<td>6.9</td>
<td>7.4</td>
<td>8.4</td>
<td>11</td>
<td>13.3</td>
<td>14.4</td>
<td>15.6</td>
<td>18.4</td>
</tr>
<tr>
<td>Total</td>
<td>268.4</td>
<td>277.3</td>
<td>289.6</td>
<td>326.4</td>
<td>374.2</td>
<td>404.4</td>
<td>435.8</td>
<td>435.8</td>
</tr>
</tbody>
</table>

But Prismark company can only provide limited forecasting data based on their existing estimation by different markets.[1] This is why they intend to develop a new forecasting model for this rapidly changing market and compare the results with their bottom up statistic data.

The purposes of this study are:

1) To develop an efficient forecasting model that provides insight into global CCL market demand and apply MAPE to find out the best forecasting model.

2) To assist CCL/PCB manufactures in making the strategy decision for future expansion and investment.

2. Literature review

Several studies have proposed time series models for industrial production and revealed the applicability of time series models to industrial production forecasting. These methods typically require large amounts of data to construct the forecasting[2]. Hsu[2] & Lin et al.[3] showed that the GM requires minimal data and is the best among all existing model for short-term prediction.

The Grey model(GM)[4,5] is applied to predict future trend in the global CCL industry, The GM has the following advantages:

1) It can be used in situation with relatively limited data down to as little as four observation

2) Just a few discrete data are sufficient to characterize an unknown system

It is suitable for forecasting in competitive environment where decision-makers only have access limited historic data. Moreover, three residual modification models were applied to enhance to enhance the GM model.

Chang et al.[6] ever applied a variable P value Rolling Grey Forecasting Model(RGM) for Taiwan semiconductor industry production. The univariate GM model makes forecast of a time series of data without considering possible correlation with any leading indicators. But for RGM, we can hypothesize to make variable P value to generate more accurate forecast. They applied real GDP by U.S. manufacturing industry from 1998-2002 and find the P equation Then average residual error can reduce from 21.27% to 12.55%. Under the same period, we applied the yearly survey of anticipated industrial production growth rate and average residual error is reduced to 10.52%.

Hsu and Wang [7,8] used grey model improved by Bayesian analysis for forecasting the output of integrated circuit industry. In this case, Bayesian method can be considered as an alternative approach to the classical approach to statistical analysis. The motivations behind adopting a Bayesian method are described as follows. First, prior knowledge or pilot information can easily be incorporated into methods. Such information is specified in a prior distribution on which inference is based. Second, the parameters in the model may be simulated directly via methods for the exploration of posterior distributions. Through BGM(1,1) assistance, we can improved MAPE from 19.63% by GM(1,1) to 8.38% by BGM(1,1) for Taiwan IC annual value for year 2002-2004.

The most famous first-purchase diffusion model in market research was the Bass innovation diffusion model which combined the modified exponential function and the logistic function diffusion
model. The Bass model[9] is well known and widely applied in developing product life-cycle curve, while also being used to forecast the sales volume of initial purchases of new products. The basic assumption of the model is that the timing of a consumer’s initial purchase is related to the number of previous buyer. Bass presumes that the initial purchase of the product is made by both “innovators” and “imitators”. Innovators and imitators are distinguished by how they are influenced by buying patterns. The number of people who have already bought the product does not influence the timing of an invocator’s initial purchase, but does influence imitators. Imitators “learn” in some sense from those who have already bought the product. Tseng and Hu[10] combine fuzzy regression with bass model to develop a quadratic-interval bass diffusion model. The empirical analysis show the quadratic –interval bass model can be applied to new products, and can reveal the best – and worst- case sales volume outcome. If the data are not sufficient, quadratic – interval bass diffusion model are potentially useful tools. However, when there is high variability in the data, the quadratic –interval bass model should not be used. Tsaur[11] applies fuzzy grey regression model, Watada’s fuzzy regression model, linear regression model and GM(1,1) to forecasting the LCD TV. Based on the empirical data analysis, fuzzy grey regression can make the good forecast and also provide the decision makers with the best and worst – possible scenarios. Wu and Chu[12]used the Gompertz, Logistic , Bass and time-series autoregressive moving average(Arma) model for Taiwan mobile telephone subscriber data analysis during 1998-2007 and found the Logistic model is superior after inflection and is better than others models.

3. Methodology

We will use Prismark historic data during 2001-2007 by different market segments then apply GM(1,1), RGM and Bass Innovation diffusion Model to analyze the data. Year 2008 data is reserved for post verification. Three forecasting models are as follows.

3.1.GM(1,1)

The Grey forecasting model GM(1,1) is a time series prediction model encompassing a group of differential equations adapted for parameter variance as well as a first order differential equation. GM(1,1) can be denoted by the following function(2).

\[ x_0^{(0)}(k) = x_0^{(0)}(1) - \frac{u}{a}(1-e^a)e^{-a(k-1)} \] \quad k = 2, 3, ..., n

where a or u is estimated using OLS. To obtain the residual modification of GM(1,1), we need to define the value of residual \( q^{(0)}(k) \),

\[ q^{(0)} = [q^{(0)}(2), q^{(0)}(3), ..., q^{(0)}(n)] \quad q^{(0)}(k) = x^{(0)}(k) - \hat{x}_0^{(0)}(k) \quad k = 2, 3, ..., n \]

According to \( q^{(0)} \), Eq.(2) denote the residual GM(1, 1). The value of \( u_q \) or \( a_q \) is estimated using ordinary least- squares(OLS).

\[ q^{(0)}(k) = q^{(0)}(1) - \frac{u_q}{a_q}(1-e^{a_q})e^{-a_q(k-1)} \quad k = 2, 3, ..., n \]

where \( q^{(0)}(1) = q^{(0)}(1) \). Combining \( \hat{q}^{(0)}(k) \) and GM(1,1) yields the residual modification of GM(1,1):

\[ \hat{x}_r^{(0)}(k) = \hat{x}_0^{(0)}(k) - \frac{u_q}{a_q}(1-e^{a_q})e^{-a_q(k-1)} \quad k = 2, 3, ..., n \]
3.2. Rolling GM(1,1)

Rolling GM(1,1) is to construct the model by creating a sequence of one-order liner moving. The first-order differential equation for the model is

\[ \frac{dX^{(1)}}{dt} + a \cdot X^{(1)} = u \]  

(5)

where \( t \) denotes the independent variables in the system, \( a \) represents the developed coefficient, and \( u \) is the Gray controlled variable. The parameters to be determined in the model are \( a \) and \( u \). Now, we define the following:

\[ X^{(0)}(i;k) = [X^{(0)}(0), X^{(0)}(i+1), X^{(0)}(i+2), \ldots, X^{(0)}(k)] \]

where \( r = k - i + 1 \)  

(6)

When \( i = 1 \), \( X^{(0)}(1;r) = [X^{(0)}(1), X^{(0)}(2), X^{(0)}(3), \ldots, X^{(0)}(r)] \)

\( r \) is the length of the rolling interval. In constructing the model, the Grey system must apply a one-order accumulated generating operation (AGO) to the primitive sequence to provide the middle message for building a model to weaken the tendency toward variation. The AGO of \( X^{(0)}(i;k) \) is defined as

\[ X^{(1)}(i;k) = \left[ X^{(1)}(i), X^{(1)}(i+1), X^{(1)}(i+2), \ldots, X^{(1)}(k) \right] = \left[ \sum_{j=i}^{i+1} x^{(0)}(j), \sum_{j=i}^{i+2} x^{(0)}(j), \ldots, \sum_{j=i}^{k} x^{(0)}(j) \right] \]  

(7)

From Eqs.(5) and(7) and the ordinary least-square method, coefficient \( \hat{a} \) becomes:

\[ \hat{a} = \begin{bmatrix} a \\ u \end{bmatrix} = (B^T B)^{-1} B^T Y_N \]  

(8)

Furthermore, the accumulated matrix \( B \) is:

\[ B = \begin{bmatrix} -[P^{(1)}(i) + (1-P)X^{(1)}(i+1)] & 1 \\ -[P^{(1)}(i+1) + (1-P)X^{(1)}(i+2)] & 1 \\ \vdots & \vdots \\ -[P^{(1)}(k-1) + (1-P)X^{(1)}(k)] & 1 \end{bmatrix} \]

where \( P \) is equal 0.5 in the original model. The constant vector \( Y_N \) is:

\[ Y_N = [X(0)(i+1), X(0)(i+2), \ldots, X(0)(k)]^T \]
The approximate relationship can be obtained by substituting \( \hat{a} \) obtained in the differential equation and solving Eq.(1) as follow:

\[
\hat{x}^{(1)}(t+1) = (x^{(0)}(1) - \frac{\mu}{a}) e^{-at} + \frac{\mu}{a}
\]  

(9)

When \( x^{(1)}(1) = x^{(0)}(1) \), the sequence one - order inverse -accumulated generating operation(IAGO) is acquired. The sequence that must be reduced as Eq.(6) can be obtained as follow:

\[
x^{(0)}(t+1) = x^{(1)}(t+1) - x^{(1)}(t) \quad t = 1, 2, ..., k,
\]  

(10)

obtain the sequence of reduction as follow:

\[
x^{(0)}(i; k) = (x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(k+1))
\]  

Where \( x^{(0)}(k+1) \) is the Grey elementary forecasting value for \( x^{(0)}(k+1) \)  

(11)

3.3. Bass Model

Bass diffusion model [9] is probably the most notable model for new product forecasting. It has been adapted for the use in forecasting a wide variety of products with short products life cycle and the new products with limited historical data. The model is:

\[
S_t = pm + (q - p) Y_t - (q / m) Y_t^2
\]  

(12)

where: \( S_t = \) Sales at time period \( t \).

\( p = \) Probability of initial purchase at time \( t = 0 \). This reflects the importance of innovators and is called the coefficient of innovation.

\( m = \) Number of initial purchases of product over the life cycle(excludes replacement purchases).

\( q = \) Coefficient of imitation representing the propensity to purchase based on the number of people who have already purchased the product.

\( Y_t = \) Number of previous buyers at time \( t \).

The generic algorithm (GA), developed by Holland in 1975, is based on the Darwinian theory of biological evolution. The main process imitated the nature genetic process, crossover, to exchange some of these individuals’ genetic data randomly to generate the offspring. In addition, GA also simulates another process, mutation, to change some of these individuals’ genetic data randomly to generate the new population. By repeating these processes until the best genes are found with the most fit. When GA evaluates the fitness value, the process would remove to selection until achieving
convergent condition. We apply GA software – EVOLVER(2000)[13] to find the p, q, m of Bass Model and MAPE(mean absolute percentage error) for global CCL market data.

3.4. Performance comparison

MAPE is selected to evaluate the accuracy of each forecasting model. The lower MAPE value shows the excellent forecasting ability by referring to Table 2.

\[
\text{MAPE (mean absolute percentage error) = } \frac{1}{n} \sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right|
\]

where \(A_t\) is actual value in period t, \(F_t\) is forecast value in period t and n is number of periods used in the calculation.

<table>
<thead>
<tr>
<th>MAPE(%)</th>
<th>Forecasting Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>Excellent</td>
</tr>
<tr>
<td>10-20</td>
<td>Good</td>
</tr>
<tr>
<td>20-50</td>
<td>Reasonable</td>
</tr>
<tr>
<td>&gt;50</td>
<td>Incorrect</td>
</tr>
</tbody>
</table>

4. Forecasting analysis for global CCL

We use Prismark historic data of global CCL demand from 2001-2007 by six market segment and 2008 demand as the actual data to compare to access the accuracy of different forecasting models. For Paper, composite, FR-4 and FR-4 high Tg market are mature market. So we apply 2001-2007 data as the histrionic period data and 2008 data as the holdout period data. FR-4 halogen free, Specialty(high speed, low loss), BT and BT equivalent and FR-5 are new market and application. So we apply 2003-2007 data as the histrionic period data and 2008 data as the verification data period.

The global CCL market can be divided into six market segments. Paper and composite products are used in products for consumers market such as radio, washing machines, refrigerators etc. FR-4 is used mainly for Cellular phones, Computer. FR-4 high Tg is for servers which are computers used in telecommunications and FR-4 Halogen free products are requested to meet new environment regulation. Specialty products are for high speed servers & communication and IC substrate application.

We utilize GM(1,1) theory for limit data base and find all MAPE by 6 market segment are over 10% and even high than 20% for FR-4 Halogen Free(27.42%).We also get the a and u value by OLS(See table 3) It shows this forecasting model is not suitable for CCL market analysis and the main reason are as follows.

2008 global economic crisis dramatically reduced all demand in 3Q and this continued into 4Q. GM(1,1) can’t sense this change by limit data base.

| Table 3. The parameter estimation of GM(1,1) by different markets |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Paper       | Composite   | FR-4        | FR-4 High Tg| FR-4 Halogen Free| Specialty(High Speed, Low Loss)| Total       |
| a           | -0.0256     | -0.0539     | -0.1111     | -0.1621     | -0.4372     | -0.1193     | -0.0965     |
| u           | 92.3978     | 10.9163     | 100.0268    | 19.9735     | 1.8157      | 9.6241      | 233.303     |
Rolling GM is by a sequence of one–order liner moving and shows better MPAE than GM(1,1). It has big improvement for paper, composite, FR-4 high Tg and total market analysis.

The most famous first purpose diffusion model in marketing research was bass diffusion model which combine the imitation and innovation rate. We apply GA model by Software EVOLVER (12) to find the p, q, m(see Table 4) then calculate MAPE for six market segments.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Composite</th>
<th>FR-4</th>
<th>FR-4 High Tg</th>
<th>FR-4 Halogen Free</th>
<th>Specialty (High Speed, Low Loss)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>2389.06</td>
<td>462.93</td>
<td>3179.13</td>
<td>1116.24</td>
<td>704.04</td>
<td>300</td>
</tr>
<tr>
<td>p</td>
<td>0.0362</td>
<td>0.0438</td>
<td>0.0034</td>
<td>0.017</td>
<td>0.0054</td>
<td>0.0252</td>
</tr>
<tr>
<td>q</td>
<td>0.0917</td>
<td>0.1538</td>
<td>0.173</td>
<td>0.218</td>
<td>0.3808</td>
<td>0.235</td>
</tr>
</tbody>
</table>

Hierarchical forecasting(HF) is a family-based forecast methodology. The two level of the global CCL market are determined by the analysis of six market segments. We apply the best data(refer Table 5) by ranking one from holdout period for each market segment to compare with the total data by bass diffusion model. It shows the bass diffusion model is better than HF for global CCL market forecast analysis (See Table 6).

<table>
<thead>
<tr>
<th>Holdout period MAPE</th>
<th>Paper</th>
<th>Composite</th>
<th>FR-4</th>
<th>FR-4 High Tg</th>
<th>FR-4 Halogen Free</th>
<th>Specialty (High Speed, Low Loss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM(1,1)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>RGM</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bass</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2008</th>
<th>HF</th>
<th>BASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holdout period MAPE</td>
<td>4.50%</td>
<td>2.80%</td>
</tr>
</tbody>
</table>

Through our detail analysis of the global CCL market by three forecasting model - GM(1,1), RGM and Bass, we found RGM to show better performance than GM(1,1) and Bass based on Table 7 and Figure1.
Table 7. Comparison of all models for historic period (MAPE)

<table>
<thead>
<tr>
<th>Historic period MAPE</th>
<th>Paper</th>
<th>Composite</th>
<th>FR-4</th>
<th>FR-4 High Tg</th>
<th>FR-4 Halogen Free</th>
<th>Specialty (High Speed, Low Loss)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM(1,1)</td>
<td>3.10%</td>
<td>4.30%</td>
<td>3.40%</td>
<td>5.70%</td>
<td>9.10%</td>
<td>0.44%</td>
<td>1.60%</td>
</tr>
<tr>
<td>RGM</td>
<td>1.80%</td>
<td>3.60%</td>
<td>1.30%</td>
<td>1.30%</td>
<td>8.10%</td>
<td>0.22%</td>
<td>0.80%</td>
</tr>
<tr>
<td>Bass</td>
<td>2.20%</td>
<td>5.10%</td>
<td>9.40%</td>
<td>5.10%</td>
<td>14.40%</td>
<td>4.20%</td>
<td>5.80%</td>
</tr>
</tbody>
</table>

Figure 1. MAPE by different forecasting models for historic periods

For holdout period MAPE, we found Bass to show the better performance than GM(1,1) and RGM based on Figure 2 and Table 8.

Table 8. Comparison of all models for holdout period (MAPE)

<table>
<thead>
<tr>
<th>Models</th>
<th>Paper</th>
<th>Composite</th>
<th>FR-4</th>
<th>FR-4 High Tg</th>
<th>FR-4 Halogen Free</th>
<th>Specialty (High Speed, Low Loss)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM(1,1)</td>
<td>10.60%</td>
<td>11.70%</td>
<td>14.20%</td>
<td>21.00%</td>
<td>7.32%</td>
<td>1.62%</td>
<td>11.40%</td>
</tr>
<tr>
<td>RGM</td>
<td>4.20%</td>
<td>4%</td>
<td>13.20%</td>
<td>7.90%</td>
<td>12.90%</td>
<td>7.82%</td>
<td>7.90%</td>
</tr>
<tr>
<td>Bass model</td>
<td>5.40%</td>
<td>3.20%</td>
<td>8.10%</td>
<td>10.00%</td>
<td>0.04%</td>
<td>0.10%</td>
<td>2.80%</td>
</tr>
</tbody>
</table>

5. Conclusions
Global CCL market forecasting is the important for CCL/PCB manufactures to make the strategic decision for future expansion and investment. It also brings valuable information and indications for future investment by products of CCL raw materials such as copper foil, glass cloth, Epoxy producers for their future investment. We used Prismark—global consultant company data —2001-2008 demand for six market segments and applied three forecasting models — GM(1,1), RGM and Bass. This is a pioneer to study this global market by different forecasting model and the key findings are as follows.

We investigate the demand forecasting model for global CCL market by GM(1,1), RGM and Bass model. GM(1,1) show good forecast accuracy of mean absolute percent error(MAPE) for historical period – 2001-2007 from 0.4% to 8.11% but the worse MAPE accuracy for holdout period —2008 from 7.32% to 22%.RGM also show the better performance than GM(1,1) but still can’t improve the MAPE accuracy for six market segments below 10%.We also use HF to apply the best data from each market segment to compare with the holdout period data from bass diffusion model. The MAPE of HF is 4.5% and is worse than bass diffusion model(MAPE=2.8%).The Bass model significantly improves MAPE for all market segment forecast for holdout period in 2008 MAPE below 10% and the lowest is 0.04% for FR-4 halogen free. In conclusions, this study shows the Bass model to have excellent MAPE improvement for holdout period in 2008 for global CCL market. It can also provide the forecasting solution for CCL/PCB manufactures for their future strategy investment.

6. References