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Forecasting the Demand for the Open Source Motion System Using Bass Diffusion Models with Patent Information

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Abstract

The demand for motion control system has grown steadily over the last decade. Especially, PLC (Programable Logic Control) technology based on IEC-61131 already use widely. The purpose of this paper is to forecast technology diffusion using patent information. First, we make an experiment with bass model and patent data. Second, we estimate suitability between forecasting and real data. Finally, we forecast that PLC technology diffusion for the next 10 years

Keywords: *Open Source Motion System, Bass Diffusion Models*

1. Introduction

As the size of the factory automation industry such as Industry 4.0 and Smart Factory grew bigger, it led to an increasing need for motion control device for automatic control and manufacturing automation machinery, ranging from simple motion control to the whole manufacturing process and more. Among various motion control technologies, PLC (Programmable Logic Controllers) based motion controllers are growing faster than others, since they are capable of immediately responding to the industry's request for decrease of manufacturing time, simplified structure, cost reduction, etc. While America and many European countries are already providing a full series of software which completely complies with international standards such as IEC-61131 or PLCOpen, there are still no such products in full compliance with PLCOpen released in the Korean market.

Currently in Korea, electronic parts researchers and manufacturing technology researchers are leading the efforts to complete the development of 'Korea Open Source Motion

System(KOSMOS)', which is fully in line with the international standard of PLCOpen, by 2016 and to provide commercialized service from 2017. The development target of 'KOSMOS' is two-pronged: first, software configuration of PC-based and imbedded motion controllers and second, open-source configuration of standardized motion control software equipped with high-speed real-time control, industrial network, motion library, KOSMO Safety, integrated handling of system information and expandability, which are essential for the software configuration. This will allow companies in Korea to have motion controllers of their own making, optimized to their applied manufacturing system. In this regard, a systematic study on the technology's demand forecast as well as consideration on technology diffusion of products should come along with technology development. Therefore, this study aims to estimate the technology diffusion of 'KOSMOS', using the Bass Diffusion Model, which is a conventional method to predict demand for new products. This dissertation consists of five chapters: chapter 1 introduction, chapter 2 characteristics of KOSMOS, chapter 3 study model, chapter 4 analysis of data acquisition method and test results, and chapter 5 meaning of this study and future direction.

2. Korea Open Source Motion System (KOSMOS)

'Korea Open Source MOtion System (KOSMOS)' enhances the effectiveness of industrial automation by providing standardized library, standard language and engineering interface, which are based on the technical specification of IEC 61131-3. KOSMOS basically supports five different languages, motion library interface, industrial high-speed network type 3 interface, 10Khz data update, and 32 axis control function. As such, it not only has generality complying with IEC 61131-3 international standard but was developed as an open motion control platform based on open source which enables users to develop a customized motion control by themselves.

3. Study Model

3.1 Bass Diffusion Model

The Bass Diffusion Model was introduced by Frank M. Bass in 1969, and has been widely used in demand forecasting as the model effectively describes S-curve life cycle of new products or services. The Bass Diffusion Model assumes that adopters of a new product consist of two groups: innovators and imitators. The innovator group is affected by advertisement or mass media and influences the early adoption of a product. Plus the imitator group is affected by both the innovator group and internal word of mouth, leading the mid- and late-adoption of the product. Figure 1 shows the analysis structure of concepts used by the Bass Diffusion Model. Assuming that a growth curve model is described from the perspective of technology diffusion, technology is developed slowly in the beginning since only a few researchers participate in research and development or since there is lack of knowledge on the overall science and the unresolved issues of engineering errors. Later, as the future potential of the technology is proposed and technological support, human effort and money begin to come in, the technology grows at an exponential rate, going through the growth phase. Finally, opportunities for the technology development are used up, gradually reaching growth limit.

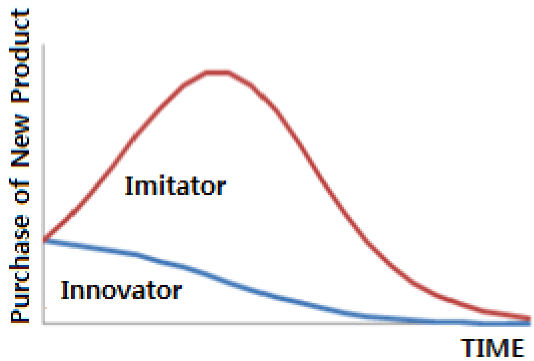

Figure 1

The Bass Diffusion Model typically derives from a hazard function. The hazard rate is the probability that a non-adopter by some specified time t turns into an adopter at the next specified time. (1) is the basic premise of the Bass Diffusion Model. Here, f(t) is a random variable function denoting time taken until the purchase was made, and F(t) is a cumulative probability function at time t.

$$\frac{f(t)}{1-F(t)} = p + qF(t) \qquad (1)$$

f(t) : Probability density function at time t

F(t) : Cumulative probability function at time t

p is coefficient of innovation denoting external influence in customers' adoption of the product, q is coefficient of imitation that the adoption is affected by imitation or learning from innovators, and coefficient m is the ultimate number of potential adopters. Assuming that m is the ultimate number of prospective customers, the number of adopters at time t is mf(t) = n(t), the accumulated number of adopters is mF(t) = N(t), and the Bass Diffusion Model can be displayed as follows;

$$n(t) = \frac{dN(t)}{dt} = p[m - N(t)] + \frac{q}{m}N(t)[m - N(t)] \qquad (2)$$

Where the definitions are as follows:

n(t) : The number of adopters at time t

N(t) : The accumulated number of adopters at time t

m : The ultimate number of adopter

p : Coefficient of innovation

q : Coefficient of imitation

Since $F(t)=\frac{N(t)}{m}$, and $f(t)=\frac{dF(t)}{dt}$, (2) can be derived from (1).

In (1), F(t) and f(t) can be derived as follows:

$$F(t)=\frac{1-e^{-(p+q)t}}{1+\frac{q}{p}e^{-(p+q)t}} \qquad (3)$$

$$f(t)=\frac{dF(t)}{dt}=\frac{p(p+q)^2e^{-(p+q)t}}{(p+qe^{-(p+q)t})^2} \qquad (4)$$

And demand n(t) and distribution N(t) are determined by the formula of coefficient of innovation p, coefficient of imitation q, and potential demand m. A demand model emerges from the estimation of the formula.

3.2 Parameter Estimation

The coefficients of the diffusion model can be estimated through utilization of early data, experience of experts, and application of similar cases. In this study, the least-squares method was applied for parameter estimation, using early performance data. The Bass Model can be described as in formula (5) if estimated by a quadratic equation through regression analysis,

$$n_t=a+bN_{t-1}+cN_{t-1}^2 \qquad (5)$$

Where the definitions are as follows:

$$a = pm, b = q - p, c = -\left(\frac{q}{m}\right) \quad (6)$$

4. Data Acquisition and Analysis

4.1 Data Acquisition

In an effort to collect data for technology diffusion forecasting of Korea Open Source Motion System, we have studied patent data of Korea, Japan, America and European countries from 2000 to 2014. 'PLC-based motion control (PLC)' was classified into the 'big' category, motion platform in the field of manufacturing automation software and motion controller in the field of the hardware were into 'middle' category, and each detailed technologies in manufacturing automation were into 'detailed' category under their relevant middle category.

Table 1

Big Category	Middle Category	Detailed Category
PLC	Motion Platform	Programming tool
		Library / Data structure
		Resource / Task management
		Network / Interface
	Motion Controller	Open controller
		Controller monitoring
		Additional functions
		Network motion controller

The yearly status quo of the collected patent data is in Figure 2. From 1989 to 2014, 894 pieces of valid data have been acquired, and in actual analysis, data from 2013 and 2014 were excluded as they were the period when there were undisclosed patents. As displayed in **Figure 2**, the number of PLC-related patents filed has begun increasing rapidly since 2000, with the relevant global market having matured already and now going downward. Korea, however, is in the introductory phase of technology diffusion with its number of patents filed growing only marginally, and lagging behind globally more than 10 years. In this study, no detailed country-by-country analysis has been conducted, but global data and Korea-specific data were used for technology diffusion forecasting.

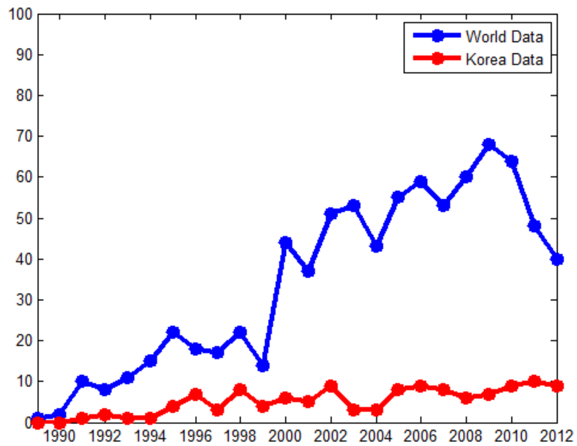

Figure 2

4.2 Bass Model Estimation

Collected patent data was divided into global and Korean data, and from there, linear regression analysis tools of MATLAB (Matrix Laboratory) were used to estimate parameters of formula (5). Again, based on derived values of a, b and c, values of p, q, and m were deduced through formula (6). Shown in **Figures 3 and 4** are the diagrams drawn with forecasting and actual values from estimated values. Further, to statistically analyze the suitability of the Bass Model, the RMSE (Root Mean Square Error) was used, and estimates were produced for each data. (See Table 2)

Table 2

Classification	RMSE
World Data	5.27
Koewa Data	3.3

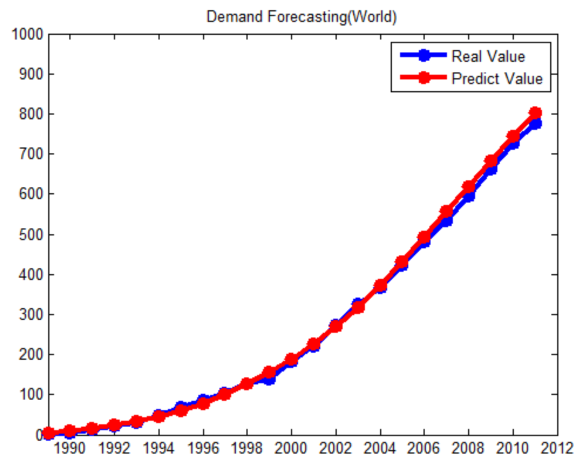

Figure 3

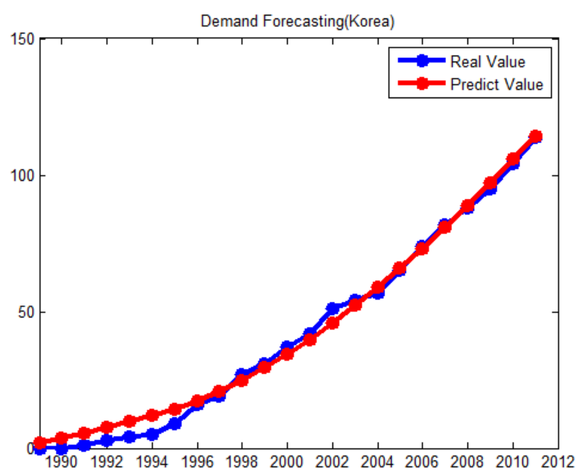

Figure 4

4.3 Technology Diffusion Forecasting

Figures 5 and 6 show the forecasting of PLC technology diffusion in Korea and the world based on the estimated Bass Model. The demand curves of both cases almost match up with those of actual data. As shown in the shapes of the graphs, KOSMOS-related technologies are currently in growth and predicted to continue to grow in the next 10 years and more.

As was seen in **Figure 5**, the global trend of diffusion of PLC-related technology has already entered the mature stage, moving past a reflection point. **Figure 6** shows that Korea's PLC-related technology trend remains in the growth phase, with the technology diffused slower than that of other countries around the globe. Also, the technology diffusion of the world will reach a saturation point at 2015 while Korea reaching it no sooner than 2035, indicating that there is more than a 10-year gap between the former and the latter. As for the forecasting of technology saturation, however, the world has produced 1,100 cases and Korea 250 cases, which is encouraging considering the size of the Korean PLC market compared to that of the global one.

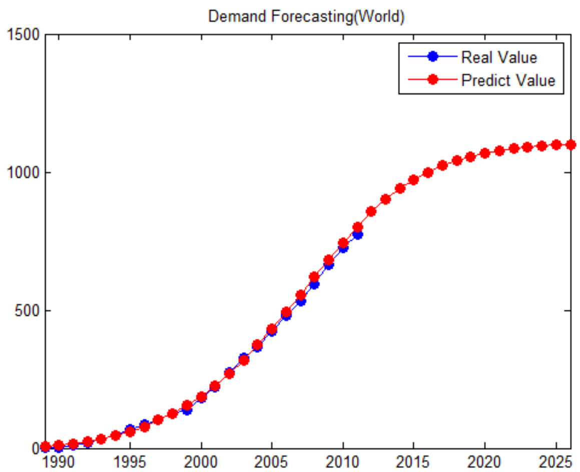

Figure 5

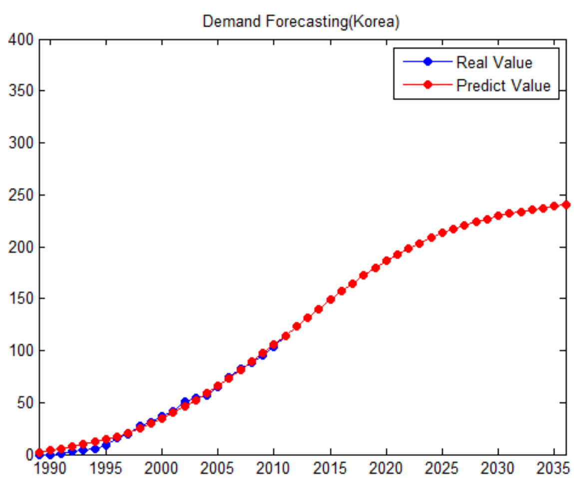

Figure 6

5. Conclusion

This study analyzed the future diffusion of technology in Korea and the world, by utilizing PLC-related patent information. Analysis results show that there is more than a 10-year technology gap between Korea and the world, and Korea's PLC-related technology is predicted to enter a mature phase only in 2030. To narrow the gap, the government is advised to make more active investment in the research and development and establish an aggressive development road map.

From the methodological perspectives, the study used the Bass Diffusion Model, a conventional demand forecasting method, and could come up with a model very similar to that of actual data. It, however, should have included the verification work done by expert groups or relevant personnel in the process of parameter estimation for the Model. As for the future direction of this study, research is required in estimating the time of diffusion of products by comparing a demand forecast based on the number of products sold with one made with patent information. In addition, further study needs to be conducted by using the Muller or Logistic Models, which could substitute the Bass Model.

Acknowledgement

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