ICIC Express Letters
Part B: Applications
Volume **10**, Number **6**, June **2019**

ICIC International ©2019 ISSN 2185-2766
pp. 533–541

FORECASTING THE DISPOSAL TREND OF END-OF-LIFE CONSUMER ELECTRONICS CONSIDERING ENVIRONMENTAL FACTORS

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Received November 2018; accepted February 2019

Abstract. *Since the introduction of Free Visit & Pickup (FVP) service by the Extended Producer Responsibility (EPR) regulation in South Korea (2013), this has been attracting consumers due to its convenient, safe and free of charge collection mechanisms. However, the constant increase in End-of-Life (EOL) consumer electronics has raised an urgent warning that the FVP service cannot operate properly if there continues to be a lack of call operators, pickup trucks, personnel and a limited budget. This study focuses on identifying the appropriate forecasting methodology which can estimate the disposal trend of EOL consumer electronics through FVP service. Time series analysis, multiple regression analysis and life cycle analysis are applied and forecasted outputs from each methodology are compared with actual field data obtained from FVP service. The multiple regression analysis that considers various environmental factors is identified as the most appropriate methodology which can forecast the expected amount of disposed EOL consumer electronics in the future.*
Keywords: Forecasting, Disposed EOL consumer electronics, FVP service, Time series analysis, Multiple regression analysis, Life cycle analysis

1. **Introduction.** As evidenced in Figure 1, an increase in personal income level and number of single household have increased the sale of various types of consumer electronics in South Korea [1,2]. However, a trend of increased weight and volume in large-size consumer electronics has generated many complaints by those responsible of properly disposing the EOL products.

The South Korean government has considered EPR regulation since 2003 for assigning proper collection and recycling methods of disposed EOL consumer electronics to manufacturers. In response to the EPR regulation, manufacturers actively started the FVP service in 2013. The FVP service is designed to eliminate the consumer's burden of disposing particularly large-size EOL products, such as refrigerator, washing machine, and TV, by dispatching pickup personnel to the homes or offices free of charge [3].

Figure 2 illustrates the amount of EOL consumer electronics disposed since EPR regulation was introduced in 2003. Disposed EOL products have increased consistently every year and a significant rise can be observed when FVP service was implemented in 2013. This trend shows that a large volume of FVP service requests will exist. Unfortunately, however, FVP service cannot operate properly if there continues to be a lack of call operators, pickup trucks, personals, and a limited budget.

Therefore, forecasting the expected amount of disposed EOL consumer electronics is an utmost priority in order to properly plan the right level of FVP service required, which includes call operators, pickup trucks personnel, and budget.

DOI: 10.24507/icicelb.10.06.533

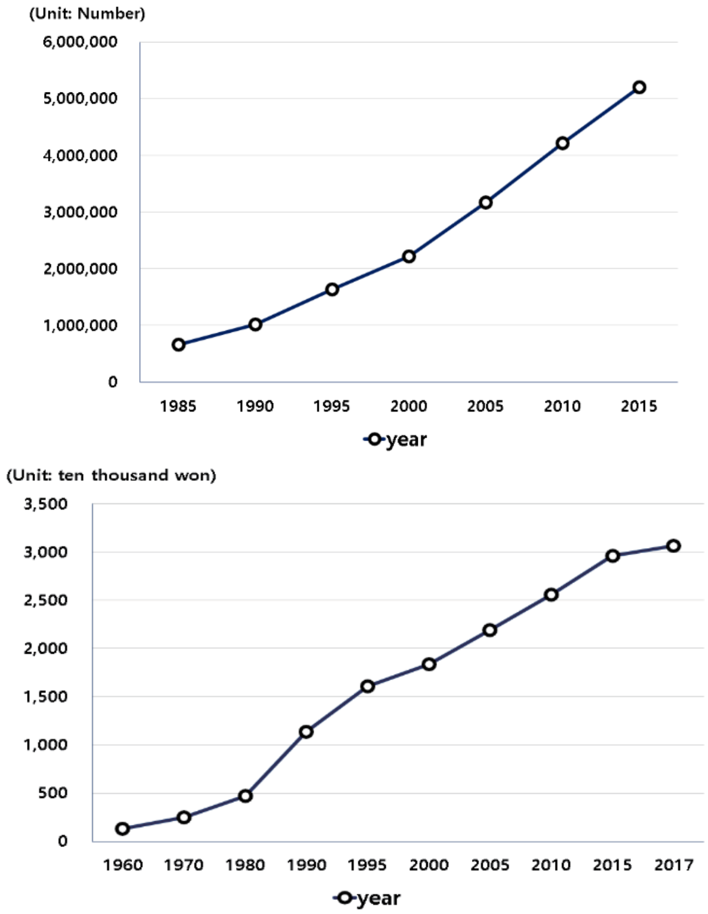

FIGURE 1. Number of single person households (Top) & GNI per capita, South Korea (Bottom)

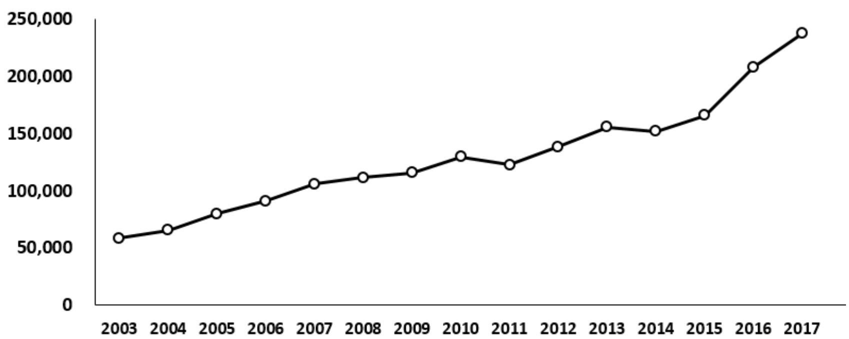

FIGURE 2. Amounts of disposed EOL consumer electronics in South Korea

This study proceeds as the following. Chapter 2 explains the scope of study and related literature review. Chapter 3 introduces three forecasting methods applied in the study and the final results are discussed in Chapter 4.

2. Scope and Literature Review.

2.1. Target and data of the study. Among many different EOL consumer electronics collected through the FVP service, this study specifically focuses on large-size products, such as refrigerator, washing machine, and TV, due to the influence of volume and weight on transportation efficiency. In order to develop appropriate forecasting models, actual FVP service field data, from January 2014 to December 2017, are applied for analysis and evaluation in this study.

2.2. **Literature review.** This study reviewed the following previous studies in hopes of identifying environmental factors relevant to the disposal of EOL consumer electronics. The selected environmental factors were applied to multiple regression analyses [4-19].

Table 1. Related literature

No.	**Year**	**Authors**	**Considered environmental factors**
1	2000	H. W. Chen and N. B. Chang [4]	Amount of disposed EOL products
2	2002	J. Navarro-Esbrı, E. Diamadopoulos and D. Ginestar [5]	Amount of disposed EOL products
3	2007	M. A. Sufian and B. K. Bala [6]	Population, amount of disposed EOL products
4	2007	G. Liu and J. Yu [7]	GDP, population, income
5	2008	S. O. Benítez, G. Lozano-Olvera, R. A. Morelos and C. A. de Vega [8]	Consumer's habit, population, education level, income, household number
6	2010	N. P. Thanh, Y. Matsui and T. Fujiwara [9]	Population, civilization level, income, size of household
7	2010	S. S. Chung [10]	Population, GDP
8	2011	S. Lebersorger and P. Beigl [11]	Population, age, tax per person, income, civilization level
9	2011	Z. Li, H. Fu and X. Qu [12]	Population, amount of disposed EOL products
10	2015	H. Fu, Z. Li and R. Wang [13]	Income per person, GDP
11	2015	I. A. Talalaj and M. Walery [14]	Population of male/female, number of employment, number of unemployment, age at employment
12	2016	M. Abbasi and A. El Hanandeh [15]	Amount of disposed EOL products
13	2016	C. Ghinea, E. N. Drăgoi, E. D. Comăniță, M. Gavrilescu, T. Câmpean, S. Curteanu and M. Gavrilescu [16]	Number of residents, age, amount of disposed EOL products
14	2016	M. Zhao, C. Zhao, L. Yu, G. Li, J. Huang, H. Zhu and W. He [17]	GDP, sale volume at retail, size of residential area
15	2017	J. L. Alfonso-Sanchez, I. M. Martinez, J. M. Martín-Moreno, R. S. González and F. Botía [18]	Age, population of male/female
16	2018	T. Suzuki, T. Shimoda, N. Takahashi, K. Tsutsumi, M. Samukawa, S. Yoshimura and K. Ogasawara [19]	Age, population of male/female, residential lifecycle

3. **Applied Forecasting Methodologies.** This study focuses on identifying the appropriate forecasting methodology that can estimate the disposal trend of EOL consumer electronics through FVP service. Time series analysis, multiple regression analysis, and life cycle analysis are applied to helping recognize proper methodology by comparing results of MAPE (Mean Absolute Percentage Error) and R^2 which are defined as below [20].

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2}{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2} \tag{1}$$

where $\overline{Y}$ = mean; $\widehat{Y}_i$ = ith forecasted value; Y_i = ith observed value.

$$MAPE = \frac{\sum_i^n \frac{|y_i - F_i|}{y_i} \times 100\%}{n} \tag{2}$$

where y_i = ith observed value; F_i = ith forecasted value.

3.1. **Time series analysis.** This forecasting methodology is applied to identifying the certain expectations of dynamic relationship throughout certain intervals in the future by introducing previous time related interval data [21].

As we can see from Figure 3, the disposal trend shows special seasonal characteristics. There seem to be more disposals during summer seasons (July and August) in comparison to other months. Therefore, Winters Additive Model, which has a good reputation in excellent seasonal data forecasting technique, is applied in this study [21].

$$L_t = \alpha(Y_t - S_{t-s}) + (1-\alpha)(L_{t-1} + b_{t-1}) \tag{3}$$

$$b_t = \beta(L_t - L_{t-1}) + (1-\beta)b_{t-1} \tag{4}$$

$$S_t = \gamma(Y_t - L_t) + (1-\gamma)S_{t-s} \tag{5}$$

$$F_{t+m} = L_t + b_t m + S_{t-s+m} \tag{6}$$

where Y_t = observed value at time t; F_{t+m} = forecasted value of time $t+m$ from time t; b_t = trend factor of time series at time t; α, β, γ = smoothing parameters; L_t = average level of time series at time t; s = length of seasonal factor; S_t = seasonal factor of time series at time t.

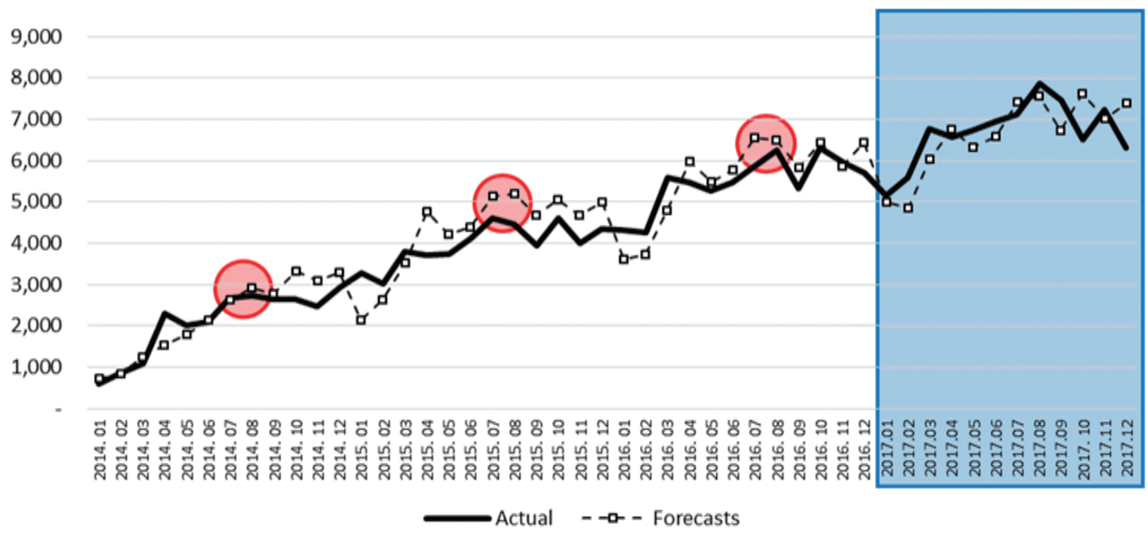

FIGURE 3. Results of time series analysis

Figure 3 illustrates the actual data from FVP services and forecasted results by time series analysis in 2017. It is evaluated that the result of MAPE is 12.70% and R^2 is 87.72% [21].

3.2. **Multiple regression analysis.** This is known as the recommended methodology for forecasting the linear relationship between one dependent variable and multiple independent variables which represent systems associate with environments related with science, engineering and social areas [22].

As independent factors, population and social factors suggested from previous literature are considered in this study. Detailed independent and dependent factors are applied at multiple regression analyses, as introduced in Table 2.

TABLE 2. Considered environmental factors

		Factors
Dependent factors		Amount of disposed large-size EOL consumer electronics through FVP service
Independent factors	Population factors	Total population number, number of moving in/out, household number, number of marriage/divorce
	Social factors	Economic level, number of real estates' trade

The important environmental factors affecting the amount of disposed large-size EOL consumer electronics through FVP service are evaluated by stepwise method in multiple regression analyses. Among multiple population factors, the total population number is evaluated as a significant factor with lower than p-value of 0.05. Also, both economic level and number of real estates' trade are evaluated as significant factors. The following model illustrates the multiple regression analyses while applying selected significant factors.

$$\begin{aligned} y = &-702{,}764 - 293 * \text{Economic level} + 0.01438 * \text{Total population number} \\ &+ 0.009028 * \text{Number of real estates' trade} \end{aligned} \quad (7)$$

Figure 4 illustrates the actual data from FVP service and forecasted results by multiple regression analyses during 2017. It is evaluated that the result of MAPE is 11.20% and R^2 is 94.26% [21].

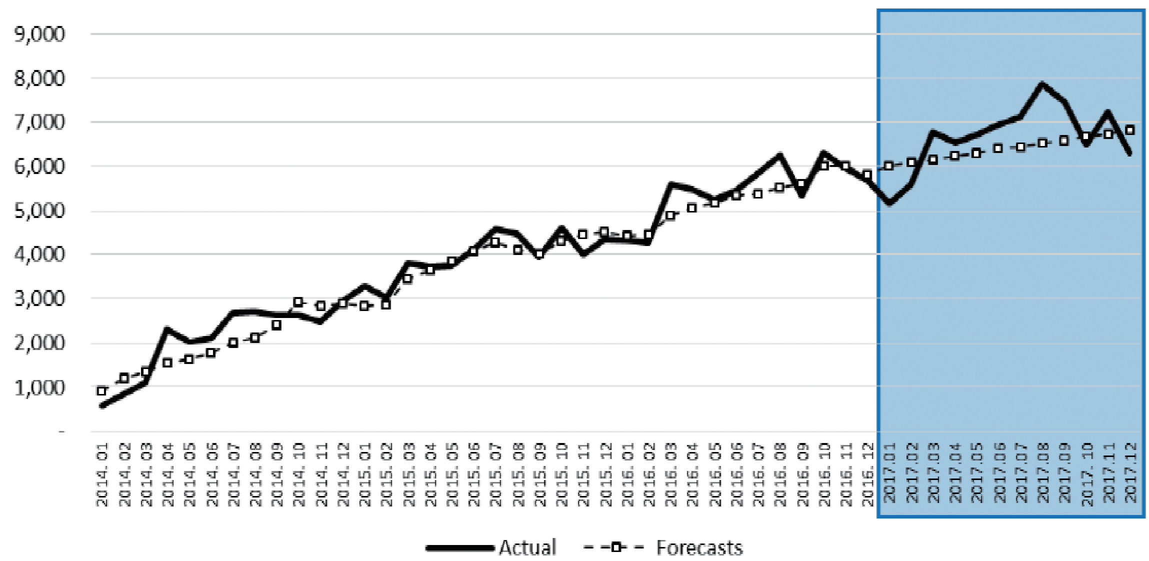

FIGURE 4. Results of multiple regression analysis

3.3. **Life cycle analysis.** Life cycle is understood as the period of product usage until disposed as EOL products. Life cycle of each consumer electronic can be defined by its function and style of usage by consumer. Therefore, actual life cycles of each disposed refrigerator, washing machine, and TV are directly observed through FVP services over two months (May and June) in 2016. Life cycle data are illustrated below in Figure 5.

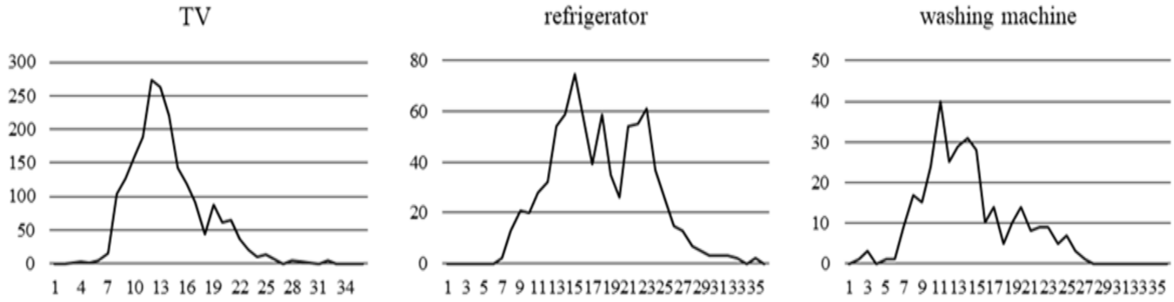

FIGURE 5. Actual observed life cycle data

The fitness levels of each probability distribution representing the life cycle of disposed TV, refrigerator, and washing machine are analyzed using the Anderson-Darling statistic value. Based on the analysis, low Anderson-Darling value can be understood as the best level of fitness for representing the observed life cycle data per EOL consumer electronic [23]. As shown in Table 3, Weibull distribution is selected for representing the life cycle of refrigerator while log normal distribution can represent washing machine and TV.

TABLE 3. Fitness levels of probability distributions

Probability distribution	**Fitness level (Refrigerator)**	**Fitness level (Washing machine)**	**Fitness level (TV)**
Weibull	**4.669**	4.548	39.313
Log normal	5.958	**2.129**	**10.086**
Exponential	186.536	64.731	499.012
Normal	5.157	5.191	33.579

The specific parameters necessary for representing each probability distribution as probability density function are identified by MINITAB (Table 4). Also, related probability density functions are illustrated in Figure 6.

TABLE 4. Probability density functions with specific parameters

	Probability density function
Refrigerator (Weibull distribution)	$\frac{1}{x\sqrt{2\pi}*0.287449}\exp\left(-\frac{(\ln x-2.58412)^2}{2*0.287449^2}\right)$
Washing machine (Log normal distribution)	$\frac{1}{x\sqrt{2\pi}*0.374100}\exp\left(-\frac{(\ln x-2.58197)^2}{2*0.374100^2}\right)$
TV (Log normal distribution)	$\frac{3.75899}{19.8489}\left(\frac{x}{19.8489}\right)^{3.75899-1}e^{-(x/19.8489)^{3.75899}}$

Figure 7 illustrates the actual observed data and forecasted results by life cycle analysis using the identified probability density functions during 2017. It is evaluated that the result of MAPE is 11.81% and R^2 is 94.65% [21].

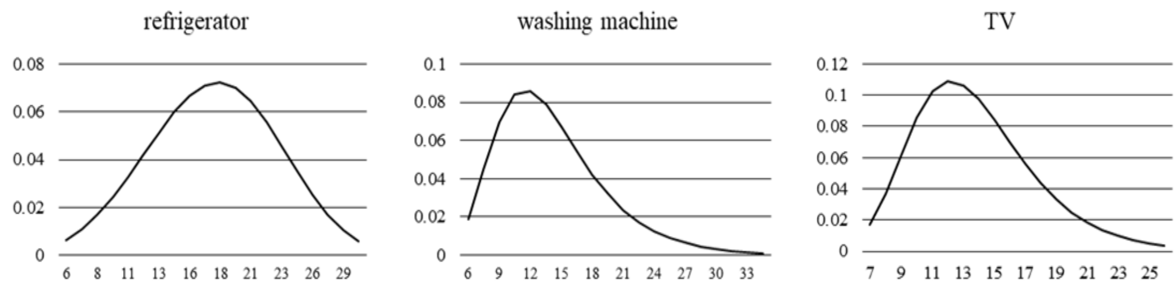

Figure 6. Probability density function for disposed EOL products

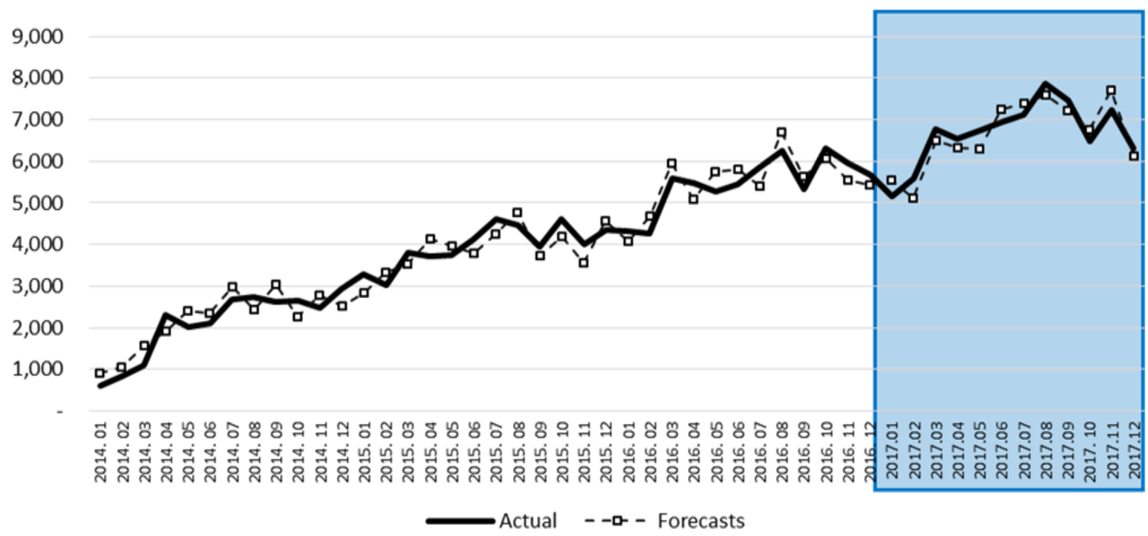

Figure 7. Results of life cycle analysis

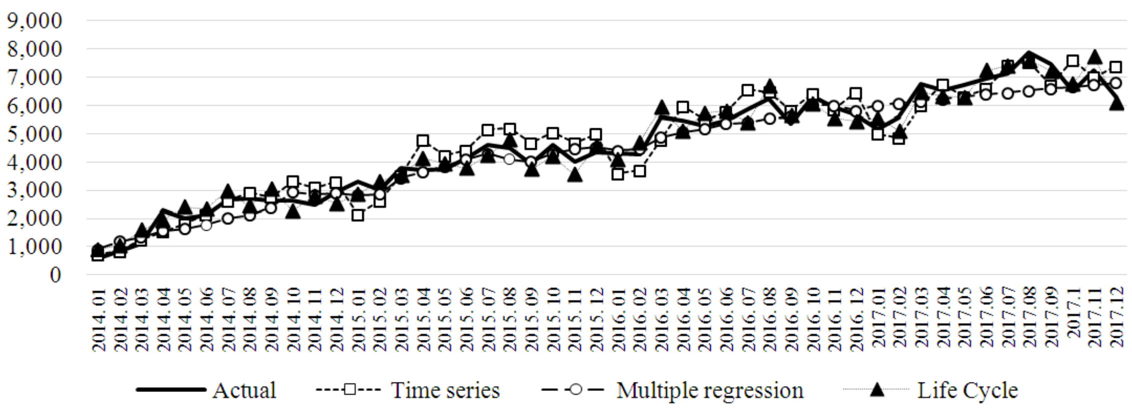

Figure 8. Comparisons of actual and forecasted data by three forecasting methodologies

4. **Discussion.** Improving the level of FVP service, which is currently operating with limited number of call operators, pickup trucks, personnel, and budget, is requested in response to the continuously increasing amount of disposed large-size EOL consumer electronics. This study focuses on identifying the appropriate forecasting methodology which can estimate the disposal trend of large-size EOL consumer electronics (refrigerator, washing machine, and TV) through FVP service. Time series analysis, multiple regression analysis and life cycle analysis are applied and forecasted outputs from each methodology are compared amongst 4 years of actual observed data, as shown in Figure 8.

Table 5. Estimation results of three forecasting methodologies (MINITAB)

Forecasting methodology	**MAPE**	R^2
Time series analysis	12.70%	87.72%
Multiple regression analysis	11.20%	94.26%
Life cycle analysis	11.81%	94.65%

The fitness levels of three forecasting methodologies are analyzed by MINITAB and summarized in Table 5. The multiple regression analysis, which considered various environmental factors, was identified as the most appropriate methodology for forecasting the expected amount of disposed large-size EOL consumer electronics in the future.

As recommended future research issue, the selection of detailed environmental factors specifically effective at certain region is needed for more accurate forecasting of disposal of EOL consumer electronics in that region.

Acknowledgment. This work is supported by Kyonggi University Research Grant 2017.

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