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Grey modelling based forecasting system for return flow of end-of-life vehicles

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ABSTRACT

Due to legislation and economic reasons, firms in most industries are forced to be responsible and manage their products at the end of their lives. Management of product returns is critical for the stability and profitability of a reverse supply chain. Forecasting the return amounts and timing is beneficial. The purpose of this paper is to develop a forecasting system for discarded end-of-life vehicles and to predict the number of end-of-life vehicles that will be generated in the future. To create the forecasting system, grey system theory, which uses a small amount of the most recent data, is employed. The accuracy of the grey model is improved with parameter optimization, Fourier series and Markov chain correction. The proposed models are applied to the case of Turkey and data sets of twelve regions in Turkey are considered. The obtained results show that the proposed forecasting system can successfully govern the phenomena of the data sets, and high accuracy can be provided for each region in Turkey. The proposed forecasting system can be used as a strategic tool in similar forecasting problems, and supportive guidance can be achieved.

1. Introduction

Growing interest in the reuse and recovery of products and materials has resulted from the scarcity of natural resources and raw materials, environmental reasons and governmental regulations about end-of-life products. Effective and efficient management of a series of activities required to retrieve a product from a customer and either recover value or dispose of it defines reverse supply chain management (Prahinski and Kocabasoglu, 2006). Managing product recovery operations efficiently is a challenging problem because of uncertainty in terms of the quantity, time and quality of the returned products. Return reasons of products can be classified as manufacturing-related returns, distribution-related returns and customer/user returns (De Brito and Dekker, 2002). For any type of return flow, assessment of the expected quantity, timing or location of return will provide insight to the managers of the reverse supply chain (Thierry et al., 1995).

Main theme of this paper is management of return flow of end-of-life products by providing a supportive forecasting tool. Forecasting the return flow of an end-of-life product is important for all decision levels of the reverse supply chain, including network design decisions at the strategic level, capacity planning decisions at the tactic level and production planning and inventory control decisions at the operational level (Toktay et al., 2003). Managing product return flows will be beneficial for the stability and profitability of a reverse supply chain.

The automotive industry is one of the largest industries in most countries because of its significant contributions to the economy. The increase in the production and sales of the automotive industry will also increase the number of end-of-life vehicles (Tian and Chen, 2014). Moreover, as reported by European Environment Agency (EEA) due to tighter environmental regulations, improvement in the environmental performance of new vehicles will result in rapid replacement of old vehicles with new ones (EEA, 2009). The European Automotive Manufacturers Association (ACEA) reported that, in 2014, 90.6 million motor vehicles were produced globally and 89.3 million vehicles were sold worldwide (ACEA, 2015).

Considering the perspective of Turkey, according to the Turkish Statistical Institute (TURKSTAT), the number of registered vehicles on the roads in Turkey increased 83.9% in the years 2004–2014 and reached nearly 19 million vehicles. The number of vehicles on the road increases by an average of 860,000 annually. In addition, in the years 2005–2014, 729,212 motor vehicles were scrapped in Turkey for recovery and recycling operations (TURKSTAT, 2015). Vehicles are strong pollutants during their useful life and at the end-of-life stage (Mahmoudzadeh et al., 2013), so a reverse supply chain should be formed to manage end-of-life vehicles' product recovery operations. In this context, forecasting the return flow of end-of-life vehicles is critical for constructing a reliable and profitable reverse supply chain (Govindan et al., 2015), and is main topic of this study. The topic is of interest to the managers and practitioners of the reverse supply chain or related economic operators.

There are important contributions in the product return flow forecasting literature. Within these contributions, several studies developed their models based on the sales data of the product, demographic information or product life cycle. Fuzzy systems, simulation models and probability

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and statistics techniques are commonly used as the solution methodology. Some of the studies validated and applied their models using empirical data sets, and other studies used real data for validation and testing. Among the studies that used real data, generally the electrical and electronic equipment waste (e-waste) data are investigated for forecasting. To the best of the authors' knowledge, studies on the product return flow management of the automotive industry and model development for end-of-life vehicles return flow for recovery and recycling operations is lacking.

This paper investigates whether an efficient forecasting model can be designed for managing return flow of end-of-life vehicles with small amount of historical data. Determining the laws governing the phenomena of end-of-life vehicle return flows is an unaddressed issue. Considering there are a number of known factors, there are also some factors that may not be known or that have complex interrelations in return flow of end-of-life vehicles. In this paper, previous observations of the return flow system are analyzed to obtain meaningful phenomena for future prediction. Other than traditional statistical models, that require large samples, this paper will provide a better understanding in modelling small sized previous observations without any prior knowledge.

Under the scope of this paper, a forecasting system for the return flow of end-of-life vehicles is developed and the system is applied to the case of Turkish automotive industry. The proposed forecasting system is based on grey system theory, which handles data sets characterized by uncertainty and small size. Although there are important contributions in the literature on forecasting with grey modelling, not much research has been conducted on return flow forecasting based on grey modelling. This study contributes to the literature with a return flow forecasting system of end-of-life vehicles based on grey modelling. The rest of the paper is organized as follows: Section 2 presents a brief literature review of related works. Section 3 presents methodology and the proposed forecasting system for end-of-life vehicles in Turkey. The studied data characteristics and experimental results are provided in Section 4. Finally, conclusions are discussed in Section 5.

2. Literature review

In the literature, several researchers have studied forecasting the return amount of products for the management of product return flow. There are also various contributions about grey forecasting systems in literature in several fields. So, the literature can be reviewed in points of product return forecasting and grey forecasting under the scope of this paper. At first part of this section, existing papers about product return flow forecasting are presented. In some of the contributions regarding with return flow forecasting, fuzzy systems or neuro-fuzzy approaches are analyzed. Some researchers used probability and statistics techniques. Some papers studied system dynamics approach, wave function, logistic model and material flow analysis or graphical evaluation and review technique for return flow forecasting.

Among the prior studies that adopted fuzzy, fuzzy expert or neuro fuzzy systems to forecast product return flow; Marx-Gómez et al. (2002) presented a forecasting method based on a simulation model, fuzzy inference system and neuro-fuzzy approach to forecast the returns of scrapped products to recycling and remanufacturing. They employed a simulation model for data generation, a fuzzy system for one-period prognosis and a neuro-fuzzy approach for multi-period prognosis. Temur et al. (2014) developed a fuzzy expert system, including fuzzy systems and genetic algorithms, to forecast return quantity in a reverse logistics network. The proposed methodology was applied to a case study from the Turkish electrical and electronic equipment recycling sector.

Hanafi et al. (2008) studied the product collection strategy for waste electrical and electronic equipment that consists of two phases: the product return forecast and the collection network. The product return forecast phase of the proposed strategy is modeled by fuzzy-colored petri net forecasting that utilizes the demographic information, age and sales data of the product. The model was verified with a case study on mobile phones. Kumar et al. (2014) studied the closed-loop supply chain network design problem, and proposed a two-phase solution methodology: adaptive network-based fuzzy inference system for product return forecasting and a network optimization model. The proposed model was applied to an experimental study.

In order to apply fuzzy, fuzzy expert or neuro fuzzy systems to prediction of product return flow, influencing factors should be discovered properly in advance, and these techniques require expert knowledge. Besides, neural network based systems require large training and testing data sets for an accurate prediction. So applying these techniques to all type of product return flows or return flows with different sources may be challenging.

Considering the product return flow forecasting models with system dynamics approach, wave function, logistic model and material flow analysis or graphical evaluation and review technique, following works are encountered in literature. Srivastava and Srivastava (2006) developed a system dynamics model that associates product returns with the number of products in use, estimated demand, product life cycle and environmental impact policies for modelling a reverse logistics network. Kumar and Yamaoka (2007) presented a system dynamics model for the Japanese automotive industry to examine the relationships between reduce, reuse and disposal using motor vehicle consumption data and motor vehicle consumption forecast data. They used Holt's linear exponential smoothing technique for forecasting. Xiaofeng and Tijun (2009) developed a forecasting model for returned products of reverse logistics based on a wave function considering periodic fluctuation.

Yu et al. (2010) addressed the problem of forecasting global e-waste (obsolete computers) generation. They used a logistic model and material flow analysis for the solution. To address the lack of lifespan data, they developed a method to determine lifespan based on stock and sales data. Agrawal et al. (2014) proposed a forecasting model based on a graphical evaluation and review technique to predict the percentage and timing of product returns. The proposed model was validated through a case study of a mobile phone manufacturing company in India.

System dynamics models or different models used in product return forecasting may require estimation of some input parameters or interviews with related stakeholders.

Among the prior works about probability and statistical models employed in product return flow prediction; Potdar and Rogers (2012) presented a forecasting methodology based on reason codes for the consumer electronics industry to forecast product returns. In their model, the return data pattern is analyzed for each return reason, and the moving average and data envelopment analysis methods are used for forecasting product returns by determined return reason. Clottey et al. (2012) developed a forecasting model to determine the distribution of the returns of used products, and integrated the forecasting model with an inventory model. They applied the proposed model to the remanufacturing operations of an electronics original equipment manufacturer. Benedito and Corominas (2013) formulated a Markov decision model to obtain an optimal manufacturing policy. The quantity of products returned is modeled as a stochastic process, where the returns in a period depend on the quantity of products sold in the preceding periods.

Krapp et al. (2013) proposed a forecasting approach based on Bayesian estimation techniques to predict the returns of a product in closed-loop supply chains. Petridis et al. (2016) developed a framework for the estimation of the global e-waste (obsolete computers) generation. In their work, different lifespan distribution types were considered for the regions, and the expected e-waste quantities were customized using the sales and lifespan data. Dynamic regressions, autoregressive models and trend models were used in the forecasting framework.