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Electronic Junk: best practice of recycling and production forecast case study in Brazil

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Abstract The concern with the disposal of waste generated by industry as well as by households is not recent. This work has sought to make a review on the production and disposal of the waste generated by electrical and electronic products, such as computers and mobile phones. Also, this review aimed to characterize the components of such waste and investigate the effectiveness of current methods of waste treatment. In addition, a tool is proposed to predict the production of computers in Brazil through the statistical method of autoregressive integrated moving average (ARIMA) models, which suggested the model ARIMA (0,0,1) to carry out the forecast. With this model, it was possible to suggest that the production of computers in Brazil, due to the global economic crisis, should continue to decrease.

Keywords: electronic junk, recycling, e-waste;

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1 Introduction

The concern with environmental degradation is not recent. There are records of not sustainable use of natural resources since two million of years B.C. and the harmful effects, as the salinization process of the soil of Sumria civilization that caused its disappearance (Monjeau et al., 2013).

Concerns with the scale of exploitation of natural resources, which in recent decades has increased exponentially, and also with the fate of residues, that are generated each time in larger quantities, been cited as potential threats to the survival of human beings (Coelho et al., 2013; Santagata et al., 2017). So, currently there is a very large effort in relation to the sustainability of our society, causing the development of products that are environmentally friendly. In 2010 the Tenth UNEP-Convention on Biological Diversity developed a resolution that enlarged the land conservation area, from 10% to 17% (Moilanen, 2012). Currently, some countries require that new products meet environmental requirements before they are approved and placed on the market (Askham et al., 2012).

A type of waste that deserves attention of society and the scientific community is the residue generated by electrical and electronic products (Borthakur and Govind, 2017). This type of waste was named e-waste or waste of electrical and electronic equipment (WEEE) by the European Union Directive 2002/96/EC (European Parliament, 2002) and it is defined as any residue composed of any part of the equipment mentioned in the directive 2002/96/EC (Li et al., 2013). In other words, the wastes are those unused or obsolete electronic devices (Man et al., 2013). This concern whether is due to, among other reasons, to the fact that this type of waste is increasing worldwide, particularly in industrialized countries, such as USA, European countries and South Korea (Jha et al., 2012).

Another reason that contributes to the concern with the e-waste is the degradation of the environment: by the high consumption of related products, whose production consumes many natural resources and contains hazardous materials; so, their destination after use becomes a key concern (Garlapati, 2016). Thus, countries have introduced laws that seek to improve recycling methods so that the level of reuse is as high as possible (Cui and Forssberg, 2003), since after the use of these products, another factor that may lead to the degradation of the environment is the inappropriate disposal of them, mainly because of its composition, with elements that are very harmful to people and also to the environment (Garlapati, 2016). Recycling e-waste material, with inadequate techniques, can cause the release of heavy metals and pollutants that can cause biomagnifcation and this is very detrimental to human health (Man et al., 2013). Considering this risk, some developed countries seek to solve their problems with this type of waste by exporting or donating used or obsolete electrical and electronic equipment to developing countries. However, many nations, which received these donations, worried about their own environment and the well-being of their population, have been exercising greater control over these activities. In January 2011, China implemented legislation that mandates producers of electrical and electronic equipment for the collection and destination of post-use products and also disciplines e-waste exports to both China and Hong Kong (Man et al., 2013).

Technology and the use of software have proved to be a useful tool in decision-making related to problems affecting the environment (Sarkar and Illoldirange, 2010. Faruk (2010) developed a hybrid neural network and ARIMA model for predicting time series of water quality. Such tools can also be useful in forecasting products that will generate e-waste, such as computers, and, consequently, assist in the planning of waste disposal. Therefore, in addition to carrying out a review in the literature on the destination of waste, mainly the electronic products, it is also the objective of this work to develop a forecast model for the production of computers in Brazil using autoregressive integrated moving average (ARIMA) models.

2 Literature Review

2.1 The Electronic Waste

New technological products are launched almost every day, especially products linked to the information industry, such as computers and cell phones (Rahmani et al., 2014). The reason for this increase is due to the great technological advance, especially in the areas of electro-electronic equipment (Jha et al., 2012); and the reduction of the acquisition prices of these products (Tanskanen, 2013). It is estimated that between 20 and 50 million tons of these wastes are generated annually (Song and Li, 2015). And every time a new product is launched, consumers, especially the younger ones, tend to buy the new product without verifying the real need to make such a purchase. As stated by Borthakur and Govind (2017), the rapid advance in technology and strong incentives for consumption bring a drastically reduced lifespan of products, rising quantity of e-waste. A direct consequence of this habit is the increase in e-waste.

The annual production of computers in Brazil has been increasing and consequently the generation of waste increases. In North America, in 2005, the obsolete personal computers produced an average of 806,700 tons of e-waste; in the European Union it averaged 594,600 tons (Li et al., 2013). Developing countries are also producing increasing amounts of e-waste, such as China which produced around 2.5 million tons in 2005 (Li et al., 2013); and because of its increasing production rate, is becoming a leader in waste storage (Song and Li, 2015). This increment in the e-waste is also perceived in Brazil.

But the most alarming fact is that although products that generate e-waste are heavily present in modern society (Zhang et al., 2012), currently there is no correct destination for them. According to Simes and Catapreta (2013), landfills remain an essential part of waste management systems and in many countries they are the only economic way for waste disposal; thus contributing to increase environmental degradation and also could endanger the health of the population (Song and Li, 2015), because the e-waste contain toxic products such as mercury, cadmium and lead, which are therefore classified as hazardous waste by the Basel Convention (Li et al., 2013). Which was adopted on 22 March 1989 and put into effect on 5 May 1992 and deals with the regulation of the export of hazardous waste (Man et al., 2013). Among the components of the e-waste, it is worth mentioning the printed circuit board (PCB) (Hadi et al., 2013). The PCB is a major component in all electrical and electronic equipment (Tanskanen, 2013), and consequently, it is employed in all such equipment (Jha et al., 2012), and is generally discarded to the landfill or incinerated (Hadi et al., 2013).

2.2 Allocation of WEEE

The ways in which countries treat their electrical and electronic waste is a matter of concern to the entire international community (Man et al., 2013). Some segments seek to reuse the largest possible percentage of waste, not only for ecological reasons, but also for economic reasons such as the recovery of valuable materials (Cui and Forssberg, 2003). Purely economic motivation, without due care for the ecological issue, can increase the risks to the environment and also the workers involved in the recycling activity (Schnoor, 2012). This can be observed in China, where considerable part of the recycling process is done in unspecified places and often by informal and even clandestine sectors (Song and Li, 2015).

Despite the risks to both the environment and the population, there are still countries that receive WEEE, such as Ghana, South Africa and the Philippines, and do not seem to have an effective recycling program for this type of waste (Li et al., 2013). They receive waste from developed countries, especially the USA, which despite being one of the largest producers of WEEE, have not yet ratified the Basel Convention (Man et al., 2013). The destination of WEEE should not be in landfills. This can lead to the diffusion of the hazardous elements mentioned to the soil, degrading the environment and placing the health of the local population at risk. For example, a printed circuit board may contain, on average, 20.13% Cu, 3.59% Al, 2.78% Zn, 2.10% Pb, 3.27% Sn, (Jha et al., 2012) and if discarded in landfills, could contaminate the soil and water in the region.

2.3 The recycling of WEEE

Despite electronics being formed by different types of materials such as glass, plastic and metals, the goal of this work is to investigate the recycling of components such as electronic and printed circuit, because these products contains harmful components to the environment, such as heavy metals, especially lead (Jha et al., 2012).

An important step in the recycling of WEEE is the identification and characterization of the waste components, in order to identify valuable materials, and especially hazardous (Cui and Forssberg, 2003). After this characterization, the material can be grinded or crushed and then the various materials that make up such parts can be separated. The separation can be done by physical methods, such as magnetic separation or density difference, or by chemical processes, such as dissolution in acid. A method of making the physical separation of the materials that make up the metal part of these wastes is to use a pyro-metallurgical process (Jha et al., 2012), also known as high temperature metal recovery (Schweers et al., 1990). To reuse metals such as copper in cables and wires of electrical and electronic products, it is common to burn these materials to eliminate the plastic part and thus reuse the metal (Man et al., 2013). However pyro-metallurgical processes, in addition to having a high cost, can increase environmental degradation by releasing toxic products and carcinogenic compounds into the air (Jha et al., 2012). An alternative to the pyro-metallurgical process, which is less costly financially and ecologically, is the chemical separation, such as the hydro metallurgical method, which is a method based on the solubilization of metals (Jha et al., 2012). Also the extraction of metals with acid and the cutting of the surrounding plastic to reuse the metal part seem to be better and less toxic alternatives than the pyrometallurgical methods (Man et al., 2013). When the objective, besides environmental, is also economic, such as recovery of rare or high-cost materials, the WEEE recycling method must take into account the characterization of the components that form such waste (Cui and Forssberg, 2003).

3 Production Forecast Model

The use of time series forecasting, which consists of the development of a mathematical prediction model, based on observations of historical data, can be a powerful tool in several areas (Khashei and Bijari, 2011; Khashei et al., 2012). When the data is complex to be modeled using a linear form, the ARIMA method is more suitable for the creation of a mathematical model (Faruk, 2010). Thus, this work has chosen to use the ARIMA model to make predictions of computer production, which is a widely used model for time series (Faruk, 2010) (HO et al., 2002); that is obtained with stochastic or deterministic process and can be represented through mathematical modeling. The first step is to build a graph with the historical data of computer production in Brazil as shown in Fig. 1. Visually it is not possible to identify any cycle in the graph formed by such data. Also, visually, it looks like the chart indicates an upward trend.

In order for the ARIMA model to be applied satisfactorily, the time series object of study must be a stationary series, that is, a series that shows neither trend nor seasonality. One way to model a time series that meets these conditions and get a satisfactory fit is to use tools that develop models whose white noise residues are randomly identically distributed. Models whose residues are not white noise, are models that tend to be autocorrelated and, therefore, predictions made by these models have little accuracy.

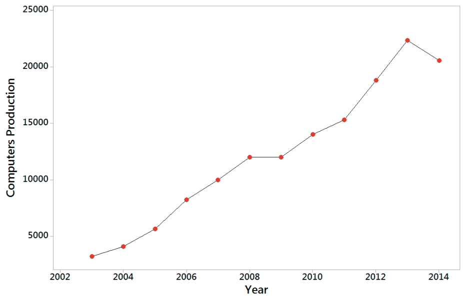

Fig. 1 Computer production in Brazil

The autocorrelation function (ACF) for the production of computers in Brazil values fall from 0.77 to practically zero and follow a sine pattern around zero. This pattern of ACF is typical of stationary time series.

Both the ACF and the Partial Auto Correlation Function (PACF) do not show significant autocorrelation except for lag one. So, both functions suggest that there is no significant trend for this time series. Thus, both the ACF and the PACF suggest the value zero for the parameter d of the ARIMA model (p, d, q), where d means how many times the series will be differentiated to make the series stationary.

Analyzing the ACF it is also possible to verify an exponential drop in the autocorrelation values. The fact of exponential fall suggests that the model that best represents this series is the autoregressive (AR) model. This is confirmed by the PACF, where there is only a significant partial autocorrelation for lag 1, thus suggesting the AR (1) model.

Analyzing the ACF and PACF functions for the residues, it was possible to observe that there is no significant correlation nor any pattern suggesting that the AR (1) model is adequate.

The time series obtained from real data are rarely stationary, also the absolute majority has some seasonal component. Although the analysis done with indicates that the best model for this series is AR (1), other models were also evaluated.

Because the parameter d is estimated as zero, the ARIMA models investigated were of the ARIMA type (p, 0, q). Among the models whose parameter $d = 0$, the ARIMA model (0, 0, 1) was the best performing, suggesting the moving average MA model (1), according to the analysis done with the MINITAB software, shown in Table 1.

Considering these results, a mathematical modeling was performed to predict the production of computers in Brazil, using the ARIMA model (0, 0, 1). Through the results it is possible to suggest that the production of computers in Brazil should decline, as already observed in the year 2014, stabilizing around a production of 12.2 million units per year.

Table 1 Final parameters estimates

Type	Coef.	Coef. EP	T	P
MM 1	-0,8664	0,2406	-3,60	0,05
Constant	12180	1896	6,42	0,000
Average	12180	1896	-	-

4 Conclusion

With the advancements in technology and the ease of acquiring electro and electronic products, the amount of e-waste is increasing worldwide. Despite this increase, much of the e-waste still lacks adequate treatment. Even some recycling practices, such as the reuse of metals through pyro-metallurgical methods, serve much more economic than environmental issues, as they end up contaminating the environment. For these reasons, a deeper investigation to develop e-waste recycling techniques are needed, so that the main objectives are more ecological than purely economic; this kind of research deserve attention of the academic community and it is proposed as future work, investigating mainly the reutilization of e-waste in new products. The use of software with mathematical and statistical methods capabilities are a valuable tool in the prediction of waste production and can provide valuable information for planning the treatment.

This work investigated the use of the ARIMA method to predict the production of computers in Brazil. The ARIMA model (0,0,1) is suggested due to the fact that the model presents p-value = 0.005, therefore smaller than 0.05, confirming that the model has a good reliability. As it is reasonable to establish a relationship of proportionality between the production of a product and the generation of waste generated by it, such a model can contribute to the planning of the treatment of future waste generated by the computers produced in Brazil.

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