MODELS FOR PREDICTING GLOBAL PLASTIC WASTE

YUEXING HAO,
GLENN SHAFER (FACULTY ADVISOR)

✷ ABSTRACT

For more than half a century, plastic products have been a part of people's lives. When plastic waste is thrown into nature, it can cause a sequence of dangerous effects. Previous researchers estimated that global plastic waste in 2020 will be more than 400 million tons. To reduce plastic waste, they built scientific models to analyze the sources of plastic and provided solutions for regenerating these plastic wastes. However, their models are static and inaccurate, which may cause some false predictions. In this paper, we first observe the distribution of the real-world plastic waste data. Then, we build simple exponential growth model and logistics model to match these data. By testing different models on our plots, we discover that the SELF-ADAPTIVE MODEL is the best to describe and correctly predict our future plastic waste production, as this model combines the benefits of SIMPLE EXPONENTIAL GROWTH MODEL and the LOGISTIC MODEL. The self-Adaptive model has the potential to minimize the error rate and make the predictions more accurate. Based on this model, we can develop more accurate and informative solutions for the real-world plastic problems.

1 INTRODUCTION

Plastic waste became a serious problem in the 21st century. According to data from 2017, scientists estimate that human beings produced around 8300 million metric tons (Mt) of virgin plastics. As of 2015, approximately 6300 Mt of plastic waste had been generated. Of this waste, only around 9% had been recycled[1]. Most plastic products are sent directly to landfills or make their way to the ocean. It may take one hundred to thousands of years for plastic products to decompose, and the available places for landfill waste are becoming fewer and fewer[2,3]. Therefore, we should prevent this global crisis from becoming more serious.

In this paper, we will introduce three models and find the model best suited for better prediction making. Based on the previous data, we will consider more factors and make the model more adaptive to the real-world situations. There are some researchers who modeled past plastic consumption and predicted the future. However, our model will be more accurate and have better data visualization.

2 METHODOLOGY

To estimate the maximum levels of single-use or disposable plastic product waste, we should first know the constraints and extent. The constraints are the EFFICIENCY of the natural environment or the waste disposal companies at processing plastic pollution. If their efficiency of disposing plastic products is higher than the rate of people producing plastic waste, there will be no plastic pollution at all. Therefore, we consider the constraint to be the availability of processing plastic waste. The extent is the RANGE of our plastic waste, since our plastic waste cannot increase to infinity. We should set an upper bound and lower bound for the weight of our waste.

The hard part of this problem is that if nations and governments do not accurately know their nation's total production of plastic waste, it increases the difficulty of managing single-use plastic waste comprehensively. The composition of modern plastic waste is complex because the waste may contain both single-use and multi-use plastics. However, we can estimate the disposable plastics product usage by finding the characteristics of plastics waste's historical change. Then, based on this trend, we can predict the quantity change of plastic waste in the future.

In addition, there emerges another difficult aspect of this problem: there are many influencing factors regarding the generation of plastic waste.

There is no simple pattern or law that can be determined by looking at the data. We should, therefore, develop a model which does not need a typical data distribution law and use less theoretical calculations that can still make an accurate prediction. That is to say, we may not need to add much mathematical functions or calculations inside the model, but the model can adaptive the different situations by itself. Therefore, in this paper, we employ the SELF-ADAPTIVE MODEL to estimate and analyze the data on plastic waste production over the past 5 to 10 years, and then predict its production in the next 30 years. It is called a self-adaptive model because this model does not have specific relationships among factors in a system. We cannot clearly indicate the relationships between the factors in the data, such as the influences of countries' rules, population density, levels of development. Thus, it is a good choice to use the self-adaptive model for this problem.

3 BUILDING PLASTIC POLLUTION MODELS

In this part, we first define plastic pollution into seven kinds of waste: Textiles, Transportation, Packaging, Electronic, Consumer Products, Industrial Machinery, Building & Construction. These different kinds of waste will be considered as different variables. Currently, plastic packaging is the greatest source of primary plastic production. Because of the rapid development of online shopping and delivery services, the demand for plastic has increased rapidly in just a few years. Thus, we can find some connections between these variables and the total amount of plastic waste[2].

To estimate the maximum mitigation levels for plastic waste without destroying the environment, we take the seven kinds of waste from different kinds of single-use or disposable plastic waste into account. Correspondingly, we consider each plastic waste factor's weights, the resources to process, the total budget, and the cost of the environmental damage it causes. We also set the damage levels for the environment to make our models more accurate. After comparing each factor, we find the best combination to maximally mitigate the dangerous effects that plastic waste brings about.

i. The Simple Exponential Growth Model

Before the 21st century, from the 1960s to the 1990s, the simple exponential growth model (also called as Malthusian Model) is a great model for describing the exponential growth of plastic waste[5]. The model could perfectly match with the data and creates great visualization.

However, after fitting the data, we discovered that plastic waste's rate of increase is not as fast after 2000. This is because nations and governments, as intervention variables, have paid more attention on this global crisis and already taken some measures to prevent more plastic pollution. To show the intervention variables, we decided to switch our models to be more accurate.

TO ESTIMATE THE MAXIMUM MITIGATION LEVELS FOR PLASTIC WASTE WITHOUT DESTROYING THE ENVIRONMENT, WE TAKE THE SEVEN KINDS OF WASTE FROM DIFFERENT KINDS OF SINGLE-USE OR DISPOSABLE PLASTIC WASTE INTO ACCOUNT.

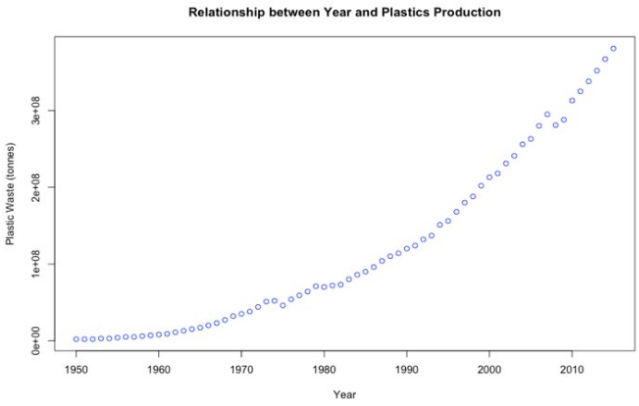

FIGURE 1: *Global plastic production per year. As shown in the figure, plastic waste was largely static from 1950-1960. After this, plastic products became prevalent in humans' lives, and plastic waste increased rapidly from 1960 onward. There were some significant increases between the 1970s and 2000s*[4].

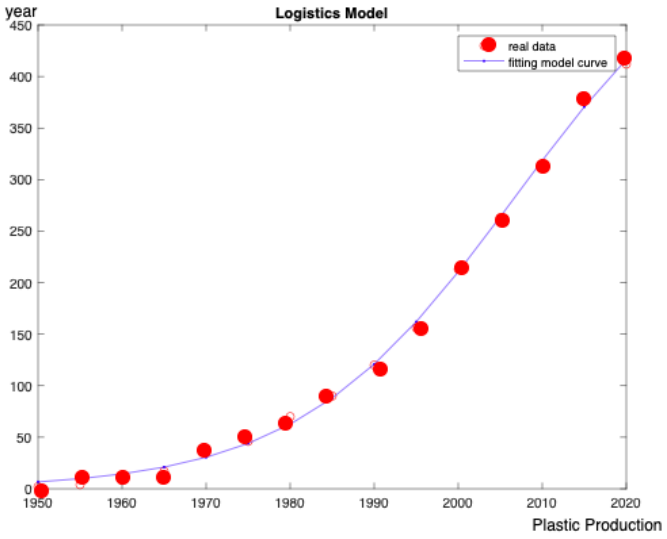

FIGURE 2: *The Logistic Model for fitting the real-world data. This plot shows that our logistic model is perfectly suited to the real data, where the x-axis represents the year, and the y-axis represents plastic production. Compared to our previous model, the logistic model is closer to the real-word data from 1960 to 2015.*

ii. The Logistic Model

The logistic model was developed by Belgian mathematician Pierre Verhulst[8]. He came up with this model's idea by thinking about the rate of population increased may be limited. It may be affected by many other factors, which may not always increase. We agree with the thoughts of Varhulst: the global plastic waste may not increase after reaching some points. Therefore, we used Logistic Model here.

However, after 2015, we observe that the model's coefficient is not a constant anymore. The curve's rate of increase will change because of intervention variables. That is to say, the model's coefficient should be a flexible number. To make the coefficient adjustable, based on our Logistic model's differential equation, we created another self-adaptive differential equation.

iii. The Self-Adaptive Model

Based on the differential equation from last section, we develop a more advanced model called a SELF-ADAPTATION model, for which the coefficients are flexible and easy to change. Some researchers call this kind of model a grey model, since it can be flexible between black model or white model. Under this model, we create a self-adaptation differential equation, which can be easily adapted in different conditions. By employing this model, our predictions are close to reality and the error is small.

Since the simple exponential growth model's predictions between 1950-1970 and Logistic model's predictions before 2010 are accurate, we will employ both models in our new self-adaptive model. The coefficient of plastic waste before 2010 is nearly static[4]. However, after 2010, when more countries and nations began to ban or limit the use of single-use or disposable plastic products, the coefficients of the plastic waste curve began to decrease. After 5-10 years, the self-adaptive model will change the coefficients, which makes it more adaptable to real-world data.

After comparison of these models, we chose to employ a self-adaptive model as our main model to predict future plastic waste production.

4 SELECTION OF THE MODELS

The criteria of model's selection are based on the accuracy of the models. (See APPENDIX 1)

- Firstly, we started by building a SIMPLE EXPONENTIAL GROWTH model and trying to find a valuable result. Before the 21st century, around 1960s to 1990s, the Malthusian model is considered a great model for describing the exponential growth since the function is proportional to the speed to which the function grows.
- However, after fitting the data, we discovered that the plastic waste's increasing rate is not that fast anymore. This is due to the fact that nations and governments, as intervention variables, paid more attention on this global crisis and already took some measurements to prevent more plastic pollutions. To show the intervention variables, we decided to switch our models to a more accurate model.

- Secondly, we built a LOGISTICS model. The logistics model matches with our real data from 1960-2015. However, after 2015, we found out that the model's coefficient is not a constant anymore. The increasing rate will also change because the intervention variables. That is to say, the model's coefficient should be a flexible number. To make the coefficient adjustable, based on our Logistics model's differential equation, we created another self-adaptive differential equation.
- Lastly, we move our eyes to the SELF-ADAPTIVE model, in which the coefficients are flexible and easy to change. Using this model, we created a self-adaptation differential equation. By employing this model, our predictions and the reality are similar, and the error is small.

Therefore, after comparisons, we chose to employ the self-adaptive model as our main model to predict the future plastic waste productions.

5 RESULTS

To examine the accuracy and efficiency of our models, we compared each year's plastic waste and the data calculated from each model. All these three models' error rates are low in the beginning before the 21st century[4]. Then, depending on the different functions, each model has some deviation from the real-world data. By graphing all the models (FIGURE 3), we can easily see the differences between the models and the best model for future prediction. Therefore, we concluded that the self-adaptive model is the most accurate one, performing much better than the simple exponential growth model or logistic model.

The strength of our model is that we take three models and use them to continue to improve the accuracy of our model. We built up the first simple exponential growth model, which gave us a general idea about the trend of plastic waste. Based on the prediction model, we came up with another Logistic model. By employing the Logistic model, the results perfectly match our data. We then tried to use Logistic model to predict our future data; however, the results deviated from the prediction data. We figured out that the problem might be the coefficients

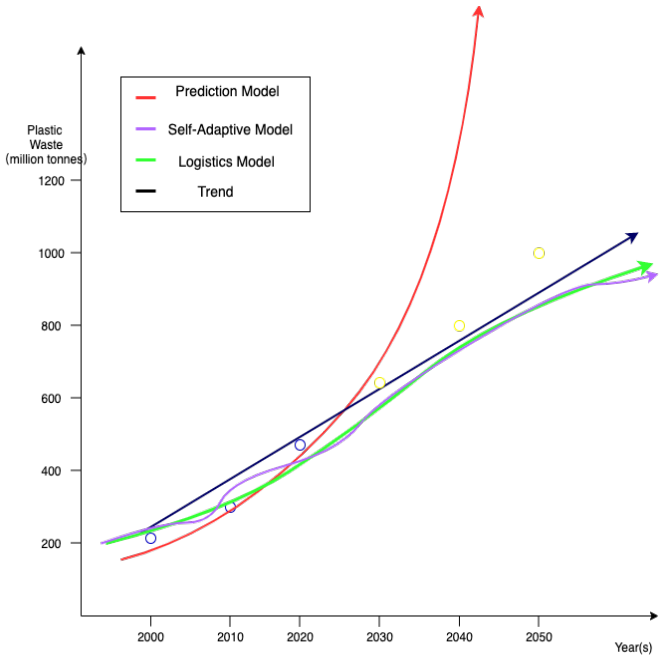

FIGURE 3: *The prediction of different models. In this figure, we can visually compare the prediction results of these three models. Blue dots represent real-world data*[4]*, and while yellow dots represent prediction data made by previous researchers*[5]*. We can clearly see that a blue linear line of a trend. This line just shows a trend of the future plastic waste but has no meaning to the predictions. The simple exponential growth model* (RED) *provides a great example of the maximum level of plastic pollution that the system can handle. It could perfectly suit current data, but not future data. The logistics model* (PURPLE) *shows the exponential growth of the prediction. After 2030, the logistics model deviates with the real-world data. The self-adaptive model* (GREEN) *displays the flexible curve which suits not only the current data, but also future data. By using a self-adaptive model, our predictions can be more detailed and precise.*

of our Logistic model, which should not be a constant. Since the coefficients are flexibly changing, we switched our model to a self-adaptive model.

6 DISCUSSION

There are a number of plastic waste prevention techniques, which can commonly be summarized as the **4 Rs**: reduce, reuse, recycle, and recover. Before, people summarized this technique as 3Rs,

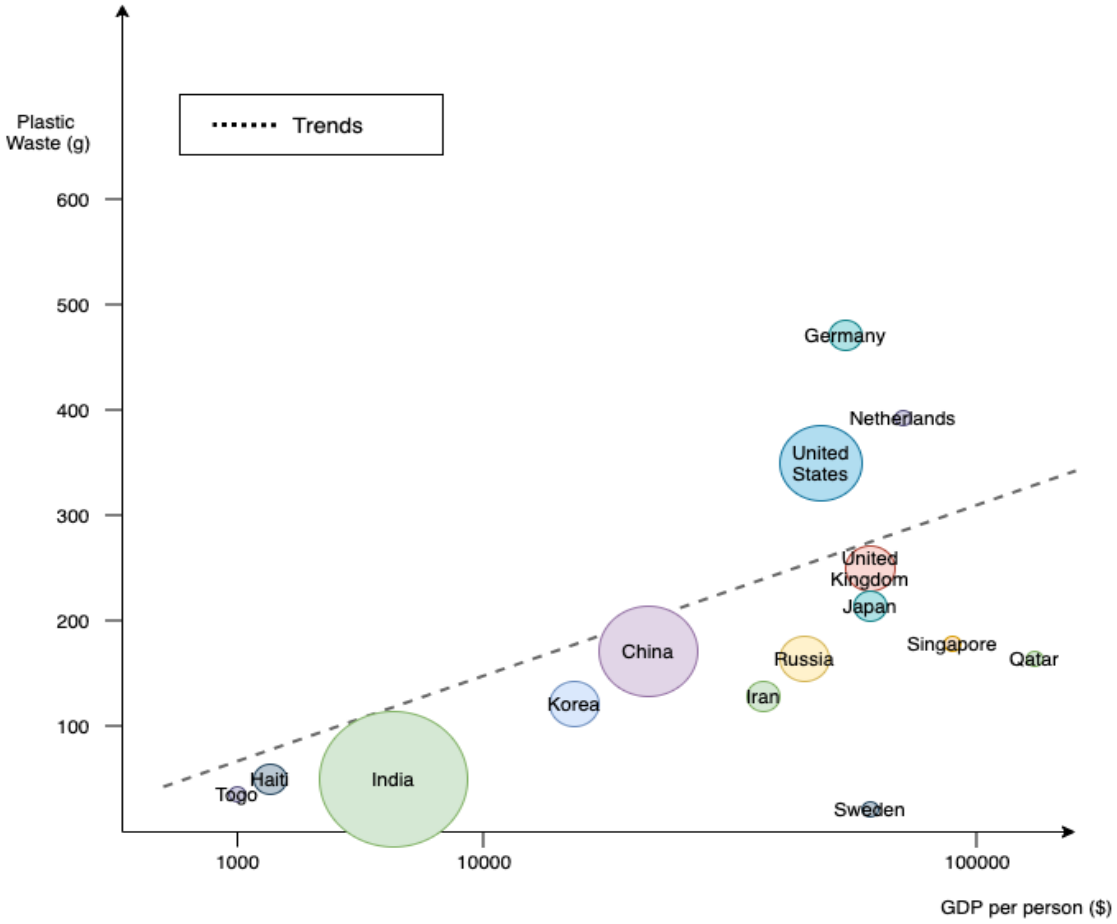

FIGURE 4: *The relationship between GDP and Plastic Waste. We choose 15 countries from different regions and development levels*[4]*. The sizes of the circles represent the total plastic waste of that country. We can conclude from the graph that when GDP goes up, plastic waste per year also increases. In the other word, the total plastic wastes have some connections with the country's degree of development.*

which did not include recovery[6]. However, more and more people are realizing that it is not enough to recycle. They also need to reduce and reuse recycled plastics.

The total population of the above 15 countries are around 5 billion, including the development and developed countries. From figure 4, we find out that developing countries usually produce less plastic waste than developed countries. All nations are responsible for managing their waste production. For example, the countries above the trend should make more actions to prevent increasing plastic waste further. Governments can design laws to prevent highly plastic polluting companies from producing single-use or disposable plastics. They can also reduce taxes for those companies that have plastic recycling technology and produce multiple-use or biodegrade plastic products. These actions could limit single-use or disposable plastic production. Moreover, they would provide a cleaner and healthier plastic cycle.

Since plastic pollution has become a global crisis, governments, companies, and human beings have realized the urgency of recycling plastic products and reducing single-use or disposable plastic. In our self-adaptive model, we predict that the rate of increase of plastic waste in 2030 and 2040 will be much slower than the previous year's rates■

7 REFERENCE

[1] Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782.

[2] Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., … & Law, K. L. (2015). Science, 347(6223), 768-771.

[3] Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. Science of the Total Environment, 566, 333-349.

[4] Hannah Ritchie and Max Roser (2020). Plastic Pollution. Published online at OurWorldInData.org.

[5] Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., ... & Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PloS one, 9(12), e111913.

[6] Lebreton, L., Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. Palgrave Commun 5.

[7] Cramer, J.S. (2002) The Origins of Logistics Regression. Chapter 9 of Logit Models from Economics and Other Fields, Cambridge University Press.

8 SUPPLEMENTARY TABLES

YEAR	PLASTIC WASTES (TONNES)	SIMPLE EXPONENTIAL GROWTH MODEL	ERROR (%)	LOGISTICS MODEL	ERROR (%)	SELF-ADAPTIVE MODEL	ERROR (%)
1960	8,000	-	-	-	-	-	-
1970	35,000	35,110	0.3143	35,069	0.1971	34,980	-0.0571
1980	70,027	70,069	0.0599	70,090	0.0899	70,431	0.0769
1990	120,383	120,443	0.0498	120,409	0.0216	120,011	-0.0390
1995	152,068	151,099	-0.6372	152,430	0.2381	151,995	-0.0480
2000	213,209	213,028	-0.0849	213,790	0.2725	213,563	0.1717
2005	263,002	263,799	0.0303	262,997	-0.0019	263,503	0.1905
2010	313,000	320,263	2.3204	320,067	0.2257	313,067	0.2578
2011	325,089	329,994	1.5088	324,989	-0.0308	325,209	0.03690.0
2012	338,797	380,863	12.4163	339,002	0.0605	338,997	590
2013	352,642	423,569	20.1130	353,059	0.1183	352,368	-0.0777
…	…	…	…	…	…	…	…
2017	368,782	457,592	24.0820	369,728	0.2565	368,597	-0.0501
2018	398,603	482,905	21.1494	399,766	0.2918	398,645	0.0105
2019	442,488	540,000	22.0372	444,050	0.3530	442,766	0.0628
2020	486,323	589,670	21.2507	487,982	0.3411	486,373	0.0461
2021	510,360	600,678	17.6970	513,480	0.6113	510,299	0.0623
2022	546,085	634,335	16.1605	546,999	0.1673	546,327	0.0443
2023	584,311	669,895	14.6470	582,994	-0.0543	583,994	-0.0542
2024	625,213	700,000	11.9618	624,785	-0.6846	625,869	0.0105
2025	668,978	724,330	8.2741	670,012	0.1546	668,321	-0.0982
…	…	…	…	…	…	…	…
2030	715,806	768,450	7.3545	715,949	0.1997	624,330	0.0529
2040	876,893	1000,785	14.1285	879,323	0.2771	823,780	0.0947
2050	1,275,997	1,868,544	46.4379	1,276,544	0.4264	1,276,544	0.0426

SUPPLEMENTAL TABLE 1: *The Comparison of Total Plastic Wastes and its Simulation based on three models*

9 SEE ALSO

HTTPS://PREZI.COM/VIEW/BJDEXJKYPKMAV4ZXQ2TZ/