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Genetic Algorithm to Estimate Parameters of Indonesian Population Growth Model

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Abstract. **In this study, the genetic algorithm is implemented to determine the most suitable growth models for Indonesian population data. The tested models are the simple models of Malthus and Verhulst. Parameters estimated in Malthus model include birth rate, death rate, and migration rate. Meanwhile, Parameters estimated in Verhulst model are intrinsic growth rate (birth rate minus death rate), carrying capacity, and migration rate. The model selection is based on the lowest average cost function value of each model. The value of the cost function is determined based on the distance between the population number in the model with the estimated parameters and the population number reported by worldbank.org. After determining the most appropriate model based on parameter estimation, simulation of the Indonesian population will be conducted for the upcoming years.**

Keywords: genetic algorithm, parameter estimation, Indonesian population, growth model

INTRODUCTION

In this study, the population growth model of the Indonesian population is examined. As reported by worldbank.org, the following are data on the number of the Indonesian population.

From the data in Table 1, it can be seen that the population of Indonesia increases continuously. Many people are curious about how the population of Indonesia in the next few years, whether it keeps getting denser. Some experts state that countries with dense populations have many advantages, namely [1-2]:

1. The huge availability of human resources
   This large amount of human resources is a benefit for a country because human resources are the most important assets for the economy, productivity, and development. It can be imagined if a country lacks domestic human resources, foreign human resources will be needed, which will lead to greater expenditure for the country.

Table 1. Number of Indonesian Population from 1960 to 2018

Year	Population Number	Year	Population Number
1960	87751068	1990	181413402
1961	90098394	1991	184591903
1962	92518377	1992	187739786
1963	95015297	1993	190851175
1964	97596733	1994	193917462
1965	100267062	1995	196934260
1966	103025426	1996	199901228
1967	105865571	1997	202826446
1968	108779924	1998	205724592
1969	111758563	1999	208615169
1970	114793178	2000	211513823
1971	117880144	2001	214427417
1972	121017314	2002	217357793
1973	124199687	2003	220309469
1974	127422211	2004	223285676
1975	130680727	2005	226289470
1976	133966941	2006	229318262
1977	137278058	2007	232374245
1978	140621730	2008	235469762
1979	144009845	2009	238620563
1980	147447836	2010	241834215
1981	150938232	2011	245116206
1982	154468229	2012	248452413
1983	158009246	2013	251806402
1984	161523347	2014	255129004
1985	164982451	2015	258383256
1986	168374287	2016	261554226
1987	171702763	2017	264645886
1988	174975954	2018	267663435
1989	178209150		

Source:worldbank.org.

2. Increasing productivity
   If human resources are managed well, then many things can be produced by the state, be it goods, services, or technology. This will certainly make developments in the country progress rapidly.
3. Increasing the spread of education
   With a dense population, the information will spread faster. This can be used in education. By utilizing the distance among residents, which are not too far away, education can be spread to the community easily and quickly.
4. Making the development of infrastructure becomes easier.
   The dense population, of course, requires a lot of facilities and infrastructure, such as health facilities, transportation, social services, roads, settlements, and others. With so many users of these facilities, infrastructure will continue to be developed. In addition, a large population will

provide more income (taxes) for the country and can be utilized for infrastructure development. With its large population, it means that the country also has many sources of labor to build infrastructure.

However, there are also a lot of thoughts that too high population density brings many disadvantages, such as [2-3]:

1. Increasing traffic jams
   Humans need transportation to reach one place to another. Many people choose to have their own vehicles because it makes them more flexible to drive anywhere and anytime. As a result, the greater the number of residents, the more the number of private vehicles will increase traffic jams.
2. Increasing pollution
   Human activities often result in waste that can pollute the environment. Vehicle fumes and factory fumes pollute the air, just as industrial waste pollutes water and soil.
3. Decreasing agricultural land
   If there are so many people in the country, the need for more settlements will also increase. This resulted in a lot of lands turned into settlements, as well as agricultural land. If agricultural land decreases, it is feared that the resources for vegetable food needs will also be reduced so that it must be imported from other countries, and this is not good for the country's economy. In addition, the rainwater catchment area will also be reduced and potentially cause flooding every time it rains heavily.
4. Many unemployment people and crime.
   Everyone has different levels of ability and skills. The more densely populated, the higher the diversity. If employment is inadequate, people with low ability and cannot compete with others are more likely to become unemployed. This triggers crime such as theft, robbery, and fraud to fulfill their needs.

For those reasons, it is essential to observe a mathematical model of population growth in Indonesia so that the government and we can prepare and anticipate the risks that might occur.

Mathematical modeling has been used to study the dynamics of population growth. In 1798, Thomas Robert Malthus introduced the simplest population growth model in the form of a dynamic system as follows [4-5].

$$\frac{dN}{dt} = bN - dN + mN \quad (1)$$

which N states population density at any time, b and d are positive constants represent the birth rate and death rate, while m is migration rate. The constant m is negative if the immigration rate is greater than the emigration rate and positive if it is otherwise. This Malthus model has a solution in the form of an exponential function. If $b - d - m > 0$, the population will grow exponentially, while if $b - d - m < 0$, the population will immediately disappear. Many assume that this model is very unrealistic because almost all living things do not grow exponentially or decrease exponentially.

Pierre-Francois Verhulst proposed that a population must grow logistically [5-6] because the growth of a population will be limited by its carrying capacity as the capacity of the natural environment and resources to support human activities to survive. With this assumption, the Malthus model (1) is modified to:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) \quad (2)$$

where $r > 0$ and $K > 0$ refer to the intrinsic growth rate $(b - d)$ and carrying capacity.

In this research, we estimate the values of the parameters of the Malthus and Verhulst models to match the population data for Indonesia. For the Verhulst model, modifications are made to consider migration, i.e.

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) - mN. \quad (3)$$

Thus, the parameters estimated in the Malthus model are $b, d,$ and m, while the Verhulst model includes $b, d, m,$ and K. The estimation of these parameters is done using the Genetic Algorithm. This algorithm has been used by many researchers to estimate parameters in mathematical models [7-10]. Anam [7] states that Genetic algorithms give us advantages in their ease of use and are able to get solutions quickly, though for high dimensional problems.

According to Carwoto [10], genetic algorithms are search algorithms based on Darwin's natural selection mechanism and genetic principles for high-quality individuals found in a domain (population). The search is carried out with an iterative procedure to regulate the population of individuals who are candidates for the solution. Goldberg [11] states that when compared with other optimization methods, Genetic Algorithms differ in four ways, namely Genetic Algorithms work with variable code structures, using multiple search points (various points), the information needed is only an objective function (thus making the implementation simpler) and using stochastic operators with a guided search.

Genetic algorithms consist of binary and continuous genetic algorithms [12]. In this study, continuous genetic algorithms are used because the variables used are in the form of decimal numbers. The difference with the binary genetic algorithm is that in a continuous genetic algorithm, there is no need to decode.

METHOD

First of all, researchers collected data on the Indonesian population several years ago from reliable sources. After that, the parameters in the Malthus and Verhulst models are estimated using the Genetic Algorithm carried out using Matlab 2018 software. In the Genetic Algorithm, some features are needed, namely generation number (number of iterations), population number (number of paired parameters), crossover point, mutation rate, and weighting constant. In this study, the generations number is 100, and population number is 200. The crossover point for each parameter's mating is random from 1 until variable (parameter) number minus 1, the weighting constant for each generation is a random real number between 0 and 1, and the mutation rate of 0.1 is selected.

In each model, an estimate of twenty experiments was carried out. From all of the experiments, the parameters with the lowest cost are selected, which have the smallest difference with real data. The next step is simulating both models using the best-estimated parameters numerically. Those two models are compared based on the error obtained also based on graphical simulations. The best model is used to predict the population of Indonesia in the next few years.

RESULT & DISCUSSION

The estimated parameters obtained from 20 experiments on the Malthus and Verhulst model are as in Figure 1 and Figure 2. The parameters that produce the smallest error of both models are summarized in Table 2. Based on the results in Table 2 and Figure 2-3, it can be concluded that the Verhulst model (logistic) is better and more suitable for real data than the Malthus model (exponential). This is in accordance with the Mathematician's assumption that the Malthus model is incompatible with natural conditions. Therefore, a numerical simulation was then performed to predict the total population and the increasing population per year in Indonesia until 2220 using the Verhulst model with four parameters producing the minimum error of birth rate (b) 0.233775, the mortality rate (d) 0.167693, the migration rate (m) 0.027557, and the environmental carrying capacity (K) 597621106. The numerical simulation is shown in Figure 4 and Figure 5.

Based on these results, the intrinsic growth rate of the Indonesian population was equal to 0.233775-0.167693=0.066082. In other words, by only considering the birth and death rates, Indonesia's population will grow by 6.6%. The positive rate of migration indicates more immigration than emigration. Furthermore, the carrying capacity of the environment, such as a wealth of food, water, availability of jobs, land, and so on in Indonesia, is predicted to be able to accommodate up to 597621106 residents.

```
Parameter estimation of Malthus model using GA
h = 0.05
number of experiments = 20
exp        b         d         m         cost
-----------------------------------------------
1.000000 0.405927 0.386538 -0.001383 1.616548
2.000000 0.228993 0.282883 -0.074662 1.616548
3.000000 0.242111 0.239599 -0.018261 1.616548
4.000000 0.299566 0.294333 -0.015540 1.616548
5.000000 0.250196 0.221330 0.008092 1.616549
6.000000 0.292906 0.308704 -0.036571 1.616548
7.000000 0.479376 0.424019 0.034584 1.616548
8.000000 0.333574 0.314186 -0.001385 1.616548
9.000000 0.374371 0.348765 0.004834 1.616548
10.000000 0.203383 0.199390 -0.016780 1.616548
11.000000 0.079676 0.118054 -0.059151 1.616548
12.000000 0.286497 0.312039 -0.046317 1.616550
13.000000 0.208444 0.225813 -0.038141 1.616548
14.000000 0.302664 0.315770 -0.033878 1.616548
15.000000 0.226611 0.247134 -0.041280 1.616631
16.000000 0.296886 0.271628 0.004486 1.616548
17.000000 0.015944 0.032089 -0.036917 1.616548
18.000000 0.206381 0.253427 -0.067814 1.616556
19.000000 0.249692 0.226235 0.002685 1.616548
20.000000 0.315186 0.279667 0.014746 1.616548
minimum
0.405927 0.386538 -0.001383 1.616548
Elapsed time is 469.920507 seconds.
```

Figure 1 : The estimated parameters for Malthus model.

```
Parameter estimation of Verhulst model using GA
h = 0.05
number of experiments = 20
exp        b         d         m          K         cost
-----------------------------------------------------------
1.000000 0.342421 0.323397 -0.019499 170.110392 0.217246
2.000000 0.343327 0.323362 -0.018465 181.809400 0.172363
3.000000 0.328225 0.281254 0.008441 424.665210 0.170913
4.000000 0.252716 0.187581 0.024864 537.403673 0.223426
5.000000 0.264109 0.200869 0.023508 536.551436 0.197419
6.000000 0.233775 0.167693 0.027557 597.621106 0.170912
7.000000 0.077399 0.055587 -0.014556 226.788606 0.299645
8.000000 0.231766 0.180088 0.012639 454.431386 0.176230
9.000000 0.345870 0.320490 -0.013717 221.558752 0.187190
10.000000 0.353678 0.302761 0.012048 451.880654 0.173308
11.000000 0.273406 0.221354 0.009618 387.134212 0.363478
12.000000 0.282550 0.227157 0.016808 499.326936 0.170983
13.000000 0.259033 0.201707 0.010186 352.558347 0.699862
14.000000 0.233600 0.154639 0.029144 441.014686 0.898003
15.000000 0.343891 0.281353 0.015588 386.754380 0.690292
16.000000 0.364340 0.326157 -0.004033 287.008327 0.346439
17.000000 0.314954 0.269362 0.006850 407.399447 0.171890
18.000000 0.221900 0.180909 0.002158 364.466131 0.172880
19.000000 0.433951 0.370792 0.022434 509.473182 0.248950
20.000000 0.291061 0.242488 0.009952 436.955919 0.171102
minimum
          0.233775 0.167693 0.027557 597.621106 0.170912
Elapsed time is 557.702023 seconds.
```

Figure 2: The estimated parameters for the Verhulst model.

Table 2. Paired Parameters with Minimum Error

Model	b	d	m	K	Error
Malthus	0.405927	0.386538	-0.001383	-	1.616548
Verhulst	0.233775	0.167693	0.027557	597.621106	0.170912

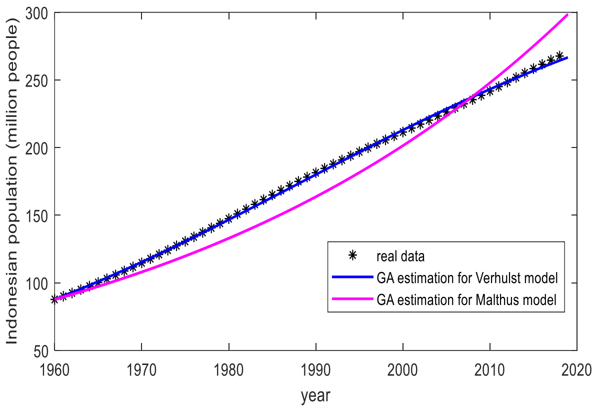

Figure 3: Numerical simulation of Malthus and Verhulst model using the best parameters pair

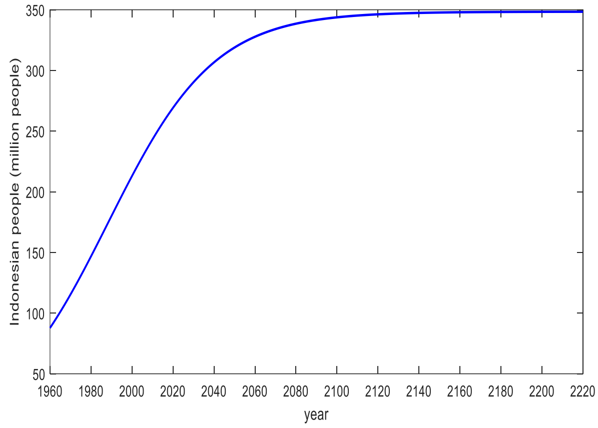

Figure 4: The Prediction of Indonesian Population until 2220

From numerical simulations, the population of Indonesia is estimated to grow logistically, and there is no significant growth again around year 2220. Population of Indonesia estimated by this program in 2391 to 2400 are 348.3404, 348.3429, 348.3453, 348.3476, 348.3498, 348.3519, 348.3539, 348.3559, 348.3578, and 348.3596 million people. It means that the increase in Indonesia's population in ten years is less than 300 people per year and continues to decline.

The graph in Figure 4 shows that the Indonesian population has the potential to reach 300 million in around 2040, which is 20 years from now. By knowing this prediction and considering the negative effects of the dense population, we can give some advice to the Indonesian government and residents as follows:

1. Promoting *Keluarga Berencana* program and mature age for marriage through premarital education.
2. Creating many jobs and effective pre-employment training.
3. Designing settlements with a sufficient amount but does not reduce agricultural land, conservation areas, nature reserves, and water catchment areas. This can be done by making flats or apartments on property intended for buildings.
4. Promoting higher education in the community. It can improve people's skills so that they can survive in the socio-economy. It can also reduce the number of early marriages.
5. Being more careful and vigilant in managing business waste to reduce air, water, and soil pollution. It aims to preserve the natural wealth, which is a legacy for future generations.
6. Persuading people to save and not exploit natural resources, especially natural resources that cannot be renewed in the near future, such as natural gas, petroleum, precious metals, coal, and so on.
7. Increasing electricity generation from renewable natural resources, for instance, water, wind, and solar panels.
8. Creating environmentally friendly vehicle fuel to reduce air pollution.
9. Creating vehicles that do not consume much space.
10. Developing public transportations which is safe, comfortable, and better to meet the needs of the community to reduce the use of private vehicles and traffic jams.

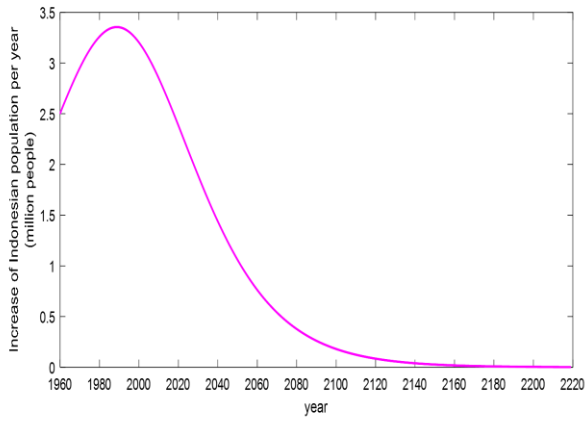

Figure 5: Prediction of Indonesian Population Increasing Per Year

CONCLUSION

Based on the results of this study, it can be concluded that Indonesia's population growth model follows the Verhulst model (logistic model) with birth rate 0.233775, mortality rate 0.167693, migration rate 0.027557, and environmental carrying capacity 597621106. Indonesia's population estimated to be stable when approaching the year 2220 with the population around 348 million. By knowing this, the government and the people of Indonesia are expected to take steps to ensure that nature and future generations can still live well even in the dense populations.

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