System Dynamics Modeling of Indonesia Population Projection Model

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Abstract. Population projections are indispensable for the planning of future development policies due to the characteristic of the data provided is periodically such as for ten years (census population, SP) and five years (inter-census population surveys, SUPAS). System Dynamics method is suitable to use for making population projections over time since it implements the feedback loop. The model uses four stages according with the age structure used: youth (0-19 years), adult (20-39 years), middle age (40-59 years), and old (60+ years). The result of total population projection shows that the difference of absolute average with United Nations (UN) projection is 0.149\% (less than BPS projection result as 0.360\%) and 0.82\% with PSKK. This result was able to improve BPS projection as 59\%. The projection result based on the age structure shows that the differences of absolute average with UN projection are 1\% (youth), 1\% (adult), 5\% (middle age), and 12\% (old).

1. Introduction
The scarcity of natural resources is certainly strongly influenced by population density. If the population density is high then the scarcity of resources will be higher [1]. Besides, technological change is dependent on the absolute level of population and, in the extensions, additionally, on the level of income and technology [2]. Population projections are indispensable for the planning of future development policies due to the characteristic of the data provided is periodically such as for ten years (census population, SP) and five years (inter-census population surveys, SUPAS). Development planning is compiled annually so the population projection data is needed to produce population data from year to year.

UN has made the projections of world population including Indonesia until 2100 using component cohort method with eight scenarios [1]. BPS has also projected the Indonesian population up to 2035 with the method that used by the UN [2]. The Center for Population and Policy Studies (PSSK) of Gadjah Mada University has also projected the Indonesian population from 2010 to 2035 with a spectrum program [3]. The Indonesian population using the component method with the development of a mixed method [4]. System Dynamic method is also used in population projection for the case of
Banda Aceh and for the Indian case [5] [6]. In this study the system dynamics method is used for the projection of population in Indonesia. The system dynamics method is used since it can provide a picture of the dynamics of the population through the model that described and by the simulation, which run in the computer [7] [8]. Both of them will help us to understand the growth of population number in the projected year. In system dynamics method we can also set the nominal growth, so we have various scenarios that can be executed to do the projection. Each scenario can help us to determine some policies. The system dynamic method can be used as a reference for projection system in Indonesia and as a comparison of projected results that have been done previously. This system dynamic modeling (SDM) method can be used as another method of pre-existing method in Indonesia.

2. Methods

2.1. Data
The population data that we use is the population of 1955-2015 from UN and the population data from the projection results by UN and BPS in 2015-2035 (UN, 2015; BPS, 2010). The population data in 1955-2015 from UN is used as baseline data to do the projection, which includes total population and population according to age structure. Meanwhile, the projected population of BPS and UN in 2015-2035 is used as a comparison of the projection result with SDM.

UN data is used because the assumptions which used by the UN have been accepted internationally. In addition, in this model the UN population initial data is used because birth data and death data used in this model comes from the UN.

2.2. Model
The collected data will be used on population projection using SDM. The modeling simulation using computer program; Stella version 9.0.2. The modeling, which used for population projection can be seen in Figure 1. There are four boxes, which represent stock variables, i.e. population of youth age, adult age, middle age, and old. There are eight flows, which represent the influencing factors of population level change, i.e. birth, become adult, become middle age, become old, youth death, adult death, middle age death, and old death.

The mathematics equation used in the stock box is the differential equation, as in the young stock box 19 years old, adult 39 years old, middle age 59 years old, and old. The example of the formula as follows:

![Figure 1. SDM for the projected population](image-url)
with $P_Y$ is the population of youth age group (0 – 19 years old), $P_A$ is the population of adult age group (20 – 39 years old), $P_{MA}$ is the population of middle-aged group (40 – 59 years old), $P_O$ is the population of old age group (more than 60 years old), $B_Y$ is the birth rate of youth age group, $B_A$ is the birth rate of adult age group, $B_{MA}$ is the birth rate of middle-aged group, $D_Y$ is the mortality rate of youth age group, $D_A$ is the mortality rate of adult age group, $D_{MA}$ is the mortality rate of middle-aged group, $D_O$ is the mortality rate of old age group, $t_Y$ is the duration of youth group to become adult, $t_A$ is the duration of adult age group to become middle age, and $t_{MA}$ is the duration of middle-aged group to become old.

Meanwhile, the flow and converter are a regular equation as in birth using equation as follows:

$$\frac{dP_Y}{dt} = P_Y B_Y + P_A B_A + P_{MA} B_{MA} - P_Y D_Y - P_Y t_Y$$  \hspace{1cm} (1)

$$\frac{dP_A}{dt} = P_Y t_Y - P_A D_A - P_A t_A$$ \hspace{1cm} (2)

$$\frac{dP_{MA}}{dt} = P_A t_A - P_{MA} D_{MA} - P_{MA} t_{MA}$$ \hspace{1cm} (3)

$$\frac{dP_O}{dt} = P_{MA} t_{MA} - P_O D_O$$ \hspace{1cm} (4)

To obtain the solution of differential equations above, integration is done by STELLA according to the projection year (2015 – 2035) as follows:

$$P_Y = \int_{2015}^{2035} (P_Y B_Y + P_A B_A + P_{MA} B_{MA} - P_Y D_Y - P_Y t_Y) dt$$  \hspace{1cm} (7)

$$P_A = \int_{2015}^{2035} (P_Y t_Y - P_A D_A - P_A t_A) dt$$  \hspace{1cm} (8)

$$P_{MA} = \int_{2015}^{2035} (P_A t_A - P_{MA} D_{MA} - P_{MA} t_{MA}) dt$$  \hspace{1cm} (9)

$$P_O = \int_{2015}^{2035} (P_{MA} t_{MA} - P_O D_O) dt$$  \hspace{1cm} (10)

UN uses TFR Indonesia data from 1950 to 2015 and some TFR Indonesia projection from 2015 until 2095. The TFR projection is taken from 600,000 possible TFR tracks counted by UN, then 60,000 TFR are selected for each country. From the selected 60,000 TFR, three kinds of TFR projection are taken: median, high, and low. This study only uses median scenario with a mid-TFR value of 60,000 TFR simulations. Median TFR value becomes the basis for determining other TFR projections.

How to make TFR Indonesia projection on system dynamic model using birth projection instead of TFR? Since the basis of TFR projection is median, the first thing to be calculated is median birth rate projection. The determination is based on TFR data in 2015 of 2.5, while the birth rate data is 0.06228, with ratio 40:1. Since the tendency median of TFR on the next period is decreasing, it is assumed that the decrease is 0.25 for the first period (2015 – 2020) and -0.4 for the second period (2020 – 2025) and +0.5 for the next period. Thus, the ratio between TFR and birth rate become 80:1 or the decrease is -0.25/80 or -0.003125 on the first period (2015 – 2020), -0.4/80 or -0.005 for the second period (2020 –
2025) and 0.5/80 or -0.00625 for the next period. The result of birth projection can be seen on Figure 2 part A. While mortality rate is assumed to remain 0.00212 (youth), 0.001982 (adult), 0.006513 (middle age), and 0.04850 (old).

3. Results and Discussion

3.1. The projection of total population

The result of total population projection shows exponential graph (see Figure 3). This exponential graph illustrates the result of population projection is continuously increasing every year. The projection result of total population in projection years has increased according to BPS, UN, and system dynamic. From 2015 to 2035 the total population continues to increase exponentially.

The result of population projection which uses SDM is almost similar with the projection result done by BPS, UN, and PSKK (see Figure 2 part B). The result of total population projection using SDM in 2015 is 257.563 million of population. By 2020, the amount is projected to increase to a total of 272.789 million of population. By 2025 the total population is increasing to 285.448 million of population. By 2030, the total population is still increasing to 296.003 million total population. By 2035 the number keeps increasing to 304.961 total population. The result of total population projection can be seen on Table 1.

![Figure 2](image_url)

**Figure 2.** (A) The determination of median variation assumption on system dynamic; (B) The result of total population projection by UN, BPS, SDM, PSKK.

| Year | SDM   | BPS   | UN    | PSKK  |
|------|-------|-------|-------|-------|
| 2015 | 257563| 255461| 257564| 254375|
| 2020 | 272789| 271066| 271857| 269145|
| 2025 | 285448| 284829| 284505| 282635|
| 2030 | 296003| 296405| 295482| 294622|
| 2035 | 304961| 305652| 304847| 304902|

3.2. The comparison of total population projection result

In comparing the projection result by SDM with by UN (as shown by Figure 3 part A) seems to fluctuate. Since 2015 is used as the early year of population projection using SDM, the percentage shows 0%. On 2020 the comparison is rising to be 0.343%, which shows that the result from SDM is greater that the projection result done by UN. In 2025 the comparative value is falling to 0.332%. The comparative result in 2030 is decreasing again to 0.177%. In 2035 the percentage keeps falling into
0.038%, which shows that the projection result of system dynamic is considered higher, yet the comparison is lower.

While comparing the projection result between SDM and BPS, the graph is falling year to year. In 2015, the value is considered high 0.655%. In 2015 the comparison is decreasing to be 0.511%. The comparative value is decreasing again into 0.125% in 2025. In 2015-2025, the projection result from SDM is considered higher than BPS projection result. The comparison in 2030 is falling again to 0.205%. In 2035, it returns to fall into -0.279%. The comparison in 2030-2035 shows that the projection result of system dynamic is lower than the result from BPS.

In comparison between the projection result by SDM and PSKK, the graph seems to fluctuate, yet it tends to keep decreasing each year. In 2015 the value is considered high 1.25%. In 2020 the comparison is rising to 1.35%. The comparison result value in 2025 is decreasing again into 1.00%. The comparative result in 2030 is falling into -0.47% in 2035 it returns to fall into 0.02%. The comparison results in 2015-2035 shows that the projection result of system dynamic is higher than the result from PSKK.

Comparing the projection result from PSKK with the one from UN, the graph is seen to increase, but the value tends to be negative. In 2015 the value is quite low at -1.24%. By 2020 the comparison results are rising to -1.00%. The value of comparison results in 2025 is rising again to -0.66%. The comparison results in 2030 is rising again to -0.279%. In 2035 it increases again to 0.02%. The comparison results of 2015-2035 shows that PSKK projection result is lower than the result of UN.

The absolute average between the system dynamic and UN is 0.149%. The absolute average between the system dynamic and PSKK is 0.82%. The absolute average between PSKK and UN is 0.64%. The absolute average between the system dynamic and the BPS is 0.355%. The absolute average between UN and BPS is 0.36%. The comparison between the system dynamic and the UN is 59% lower than the comparison between UN and BPS. In other words, the system dynamic model can improve the projection of BPS by 59% if it is compared with the projection of the UN.

3.3. Population based on age group

The result of total population projection based on age group using SDM method can be seen on Figure 3 part B. Basically, each group has different chart pattern. The age group of 0-19 years old is decreasing each year. The age group of 20-39 years old, 40-59 years old, and 60+ years old are increasing each year. The population structure described on Figure 5 shows that the population number of 0-19 years-old age group is more than the number of other age group.

![Figure 3. (A) The comparison of projection result of total population; (B) Projection result of total population based on age group](image-url)

The projection result of total population according to age group using system dynamic is as follows: in 0-19 years-old age group the number is 94,262,960 by 2015, then it decreases in 2035 to 92,086,480. The total population of 20-39 years-old age group is 82,275,650 in 2015, and it is increasing by 2035 into 89,945,690. The number of people in 40-59 years-old age group is 59,830,760 in 2015, and by 2035 it is predicted to increase into 71,824,570. Total population of 60+ years-old age
group increases to 21,194,437 in 2015, and by 2035 it is predicted to increase to be 51,105,220. This result can be seen on Table 2.

**Table 2. Projection result of population according to age group (Part 1)**

| Age   | 2015   | SDM   | 2020   | SDM   | 2025   | SDM   |
|-------|--------|-------|--------|-------|--------|-------|
| 0-19  | 91952.8| 94262.96| 94262.96| 93106.2| 94863.77| 93211.4|
| 20-39 | 82522.7| 82275.65| 82275.65| 84275.9| 85244.6| 85876.8|
| 40-59 | 59255.8| 59830.76| 59830.76| 66596.6| 66601.29| 72045 |
| 60+   | 21685.4| 21194.437| 21194.437| 27087.7| 26174.36| 32160.76|
| Total | 255416.7| 257563.815| 257563.91| 257563.815| 271857.4| 284505 |

**Table 2. Projection result of population according to age group (Part 2)**

| Age   | 2030   | 2035   |
|-------|--------|--------|
| 0-19  | 91726.9| 91471.04|
| 20-39 | 88064.8| 90963.49|
| 40-59 | 75657.7| 76474.68|
| 60+   | 40955.7| 45937.89|
| Total | 296405.1| 304961.96|

3.4. The comparison of projection result of population based on age group

The comparative percentage of projection result shown in Figure 4 shows varied results among the three comparisons on each age group. The age group of 0-19 years old on the comparison between system dynamic and UN from 2020-2030 has negative value while in 2035 has positive value. With the same age group, the comparison between system dynamic and BPS from 2020-2035 has positive value. The age group of 20-39 years old on the comparison between system dynamic with UN and system dynamic with BPS from 2020-2030 has positive value while in 2035 has negative value. The age group of 30-59 on comparison between system dynamic with UN and system dynamic with BPS from 2020-2035 has negative value. The age group of 60+ years old on comparison between system dynamic with UN and system dynamic with BPS from 2020-2035 has positive value.
The absolute average between the system dynamic and the UN for the population of 0-19 years-old age group is 0.89%. The absolute average population of 20-39 years age group is 1.22%. The absolute average of the population in the age group of 40-59 years old is 5.30%. The absolute average of population of 60+ years-old group is 12.37%.

The absolute average between system dynamic and BPS for population of 0-19 years-old age group is 1.54%. The absolute average population of 20-39 years-old age group is 0.93%. The absolute average of the population in the age group of 40-59 years old is 5.93%. The absolute average population of 60+ years-old group is 8.78%.

The absolute average between UN and BPS for population of 0-19 years-old age group is 2.11%. The absolute average population of 20-39 years-old age group is 0.41%. The absolute average population of the age group of 40-59 years is 5.93%. The absolute average population of 60+ years-old group is 8.78%.

4. Conclusions
Dynamic system can be used to model the projection of Indonesian population both totally and by age group. The total projection of population uses dynamic system to fix BPS projection by 59% if it is compared to the UN projection. In 2035 the difference between the system dynamic and UN is 0.038%. The difference between the system dynamic and PSKK is 0.02%. The difference between the system dynamic and the BPS is -0.279%. In 2035 the result of total population projection using system dynamic modeling closer to the PSKK results. The projection of population according to age group generates differences in absolute average with the result of UN is 0.89% (youth), 1.22% (adult), 5.30% (middle age), 12.37% (old). The dynamic system model can be used as the method in projection of population. On the dynamic system we also have control to adjust the desired growth nominal, so we can have various scenarios that can be executed to do the projection. The assumption used on the model needs to be adjusted with the existing population data in Indonesia if it is to be used at a level below national level, because the migration assumption on this model has not been used.

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