Analysis of which factors are important in controlling the number of smokers in Indonesia

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\textbf{Abstract.} The number of smokers in Indonesia is increasing, making the quality of health of the Indonesian population decrease. In addition, the age of smokers in Indonesia is also getting early. This paper discusses the problem of smoking in Indonesia by dividing the population of non-smokers, smokers, and ex-smokers divided into a population of teenagers and adults. First we will construct a mathematical model for this problem, then we get differential equation system. Next, a sensitivity analysis is carried out to get information about which factors are most important in controlling smoking.

1. Introduction

Ministry of Health data [1] shows an increase in the prevalence of smokers from 27\% in 1995, increasing to 36.3\% in 2013. This shows that 20 years ago, every 3 Indonesians one was a smoker, in the year 2013 from every 3 Indonesians, 2 of whom were smokers, and this still happens today. Smoking habits are not only done by adults, but also by teenagers. Reporting from the Ministry of Health data, the bad habits of smoking carried out by teenagers also increased. Ministry of Health data shows that the prevalence of teenagers aged 16-19 years have increased 3-fold from 7.1\% in 1995 to 20.5\% in 2014. In addition to the increase in the number of teen smokers, teenagers who start smoking are also getting early. This is indicated by an increase in novice smokers aged 10-14 years, the increase is more than 100\% in less than 20 years, from 8.9\% in 1995 to 18\% in 2013. Unfortunately, the increase in the number of smokers in Indonesia can cause a decrease quality of health of the population of Indonesia, because smoking is not good for human health.

Smoking is one of the biggest factors that causes various diseases. A smoker has a 2 to 4-fold risk of developing coronary heart disease and has a higher risk of developing lung cancer and other non-communicable diseases. The bad habit of smoking will have an even worse effect if people are lazy to move or lack exercise, unhealthy and unbalanced diets, or consume alcohol. In addition, smoking makes a decline quality in health which has resulted in a decrease in the quality of children and the newly born generation. The decline in the quality of the nation’s next generation causes in ongoing duping and impoverishment from generation to generation.

The facts that have been shown encourage writers to analyze how the interaction of human behavior that causes the increase of smokers in Indonesia by analyzing the mathematical model of smoking behavior. The mathematical model of smoking behavior was first introduced by C
Castillo-Garsow, G Jordan-Salivia, and A Rodriguez-Herrera (1997) [2] by dividing the human population into three classes, namely non-smokers, smokers, and ex-smokers, which were then known as NSE smoking behavior model. In 2008, O Sharomi and A B Gumel [3] developed the smoking behavior model by dividing the class of ex-smokers into two types, namely ex-smokers who stopped temporarily and ex-smokers who quit forever. Furthermore, L Pang, Z Zhao, S Liu and X Zhang (2015) [4] investigated the smoking behavior model by dividing the population of ex-smokers into temporary ex-smokers and permanent ex-smokers. In this model, Pang et al included the component of mortality rates by assuming the mortality rates of all class were same. However, these assumptions are not appropriate because the mortality rates of non-smokers, smokers, and ex-smokers certainly different according to the facts in the health sector.

Subsequent research in 2017, Sikander, Khan, Ahmed, and Mohyud-Din [5] examined NSE smoking behavior by dividing the population of smokers into normal smokers and excessive smokers. Kasbawati (2017) [6] investigated NSE smoking behavior by dividing it into two cases, namely the case for the male population, and the case for the female population, then the two cases compared the results. Furthermore, in 2018 the NSE smoking behavior model was developed by Simarmata C M D, Susyanto N, Hammadi I J, and Rahmaditya C [7] to look at the effect of differences in pure mortality rates by dividing the population into three classes namely non-smokers, smokers, and ex-smokers. Based on research on existing smoking behavior models do not divide the population of teenagers and adults, while the fact that there is an increase in the population of teenagers who smoke or beginner smokers is quite significant. This encourages the writer to examine the NSE smoking behavior model by dividing each sub-population into two classes, the teenagers class and adult classes, so that the population will be divided into six sub-populations. The six sub-populations are young non-smokers, young smokers, ex young smokers, adult non smokers, adult smokers, and ex adult smokers. In this model, young population means teenager population. Then, the mortality rates of each class that used in this model are different according to the facts in the health sector. We will construct a mathematical model from this problem, and then we concern to analyzing which parameter that important in controlling smoking.

2. Construction of the mathematical model

In this section, we present a mathematical model to describe smoking behavior. In the smoking behavior model, population is divided into six sub-populations. The six sub-populations are young non-smokers, young smokers, ex young smokers, adult non smokers, adult smokers, and ex adult smokers. Then, young non-smokers, young smokers, ex young smokers, adult non smokers, adult smokers, and ex adult smokers, eachs are denoted by $N_Y$, $S_Y$, $E_Y$, $N_A$, $S_A$, and $E_A$. In this study, we make following assumptions:

- The transition parameter is constant over time because the smoking behavior model is only observed for a certain period of time.
- Everyone in a sub-population can interact with people in all other groups.
- The transition between sub-populations S and E is proportional to the size of the sub-population.
- The transition from N to S occurs because of the interaction and influence of smokers to non smokers.
- The pure mortality rate for each class varies. In the young non-smokers, young smokers, ex young smokers, adult non smokers, adult smokers, and ex adult smokers are each symbolized by $\beta_N$, $\beta_S$, $\beta_E$, $\delta_N$, $\delta_S$, and $\delta_E$. Note that $\beta_N < \beta_E < \beta_S$ and $\delta_N < \delta_E < \delta_S$ with $\beta_i < \delta_i$ for $i = N, S, E$.
- There is no migration in this population.
• The size of the population is fixed.
• The population is not differentiated by gender.
• The other factors, that is advertising factors, cigarette prices, and warnings on cigarettes are not considered.
• The mortality rate in class \( i \) satisfies the following equation \( f_i(P(t)) = \beta_i + \lambda P(t) \) for young population, and \( f_i(P(t)) = \delta_i + \lambda P(t) \) for adult population, for \( i = N, S, E \), with \( \lambda \) is density-dependent mortality rate.

In forming the mathematical model of smoking behavior, we use the following parameters:

| Parameter                                                      | Symbol |
|---------------------------------------------------------------|--------|
| Population birth rate                                        | \( \alpha \) |
| Pure mortality rate of young non-smokers                     | \( \beta_N \) |
| Pure mortality rate of young smokers                         | \( \beta_S \) |
| Pure mortality rate of young ex-smokers                      | \( \beta_E \) |
| Pure mortality rate of adult non-smokers                     | \( \delta_N \) |
| Pure mortality rate of adult smokers                         | \( \delta_S \) |
| Pure mortality rate of adult ex-smokers                      | \( \delta_E \) |
| The rate of change of young non-smokers becomes young smokers | \( \gamma_Y \) |
| The rate of change of adult non-smokers becomes adult smokers | \( \gamma_A \) |
| The rate of young smokers quit smoking when they were teenager | \( \mu_Y \) |
| The rate of adult smokers quit smoking                       | \( \mu_A \) |
| The rate of young ex-smokers who smoke again when they were teenager | \( \omega_Y \) |
| The rate of adult ex-smokers who smoke again                  | \( \omega_A \) |
| The rate of young becomes adult                              | \( \tau \) |
| The rate of young non-smokers still does not smoke until adult | \( \rho \) |
| The rate of young smokers still smoke until adult             | \( \theta \) |
| The rate of young ex-smokers still does not smoke until adult | \( \eta \) |
| Density-dependent mortality rate                              | \( \lambda \) |

Based on the assumptions and parameters that have been given, a compartment diagram of the smoking behavior model presented in Figure 1 is formed as a reference in model formation.

Figure 1 represents a mathematical model formed from a system of differential equations. Solutions of systems of differential equations describe changes in population over time \( t \), in years). For further \( P(t), N_Y(t), S_Y(t), E_Y(t), N_A(t), S_A(t), E_A(t), f_i(P(t)) \), respectively, are sufficiently written \( P, N_Y, S_Y, E_Y, S_A, N_A, E_A, f_i \). The system of differential equations of the
smoking behavior model in figure 1 is

\[
\begin{align*}
\frac{dN_Y}{dt} &= \alpha P - f_{N_Y} N_Y - \gamma_Y \frac{S_A + S_Y}{P} N_Y - \tau \rho N_Y - \tau (1 - \rho) \frac{S_A + S_Y}{P} N_Y \\
\frac{dS_Y}{dt} &= \gamma_Y \frac{S_A + S_Y}{P} N_Y + \omega_Y E_Y - f_{S_Y} - \mu_Y S_Y - \tau S_Y \\
\frac{dE_Y}{dt} &= \mu_Y S_Y - f_{E_Y} E_Y - \omega_Y E_Y - \tau E_Y \\
\frac{dN_A}{dt} &= \tau \rho N_Y - f_{N_A} N_A - \gamma_A \frac{S_A + S_Y}{P} N_A \\
\frac{dS_A}{dt} &= \gamma_A \frac{S_A + S_Y}{P} N_A + \tau (1 - \rho) \frac{S_A + S_Y}{P} N_A + \tau \theta S_Y + \tau (1 - \eta) E_Y + \omega_A E_A - f_{S_A} S_A - \mu_A S_A \\
\frac{dE_A}{dt} &= \mu_A S_A + \tau (1 - \theta) S_Y + \tau \eta E_Y - \omega_A E_A - f_{E_A} E_A
\end{align*}
\]

Figure 1. Smoking Behavior Diagram Transition

Total population \( P = P_A + P_Y \) with \( P_Y = N_Y + S_Y + E_Y \) and \( P_A = N_A + S_A + E_A \), then from equation system 1 we get

\[
\frac{dP}{dt} = \lambda P - f_{N_Y} N_Y - f_{S_Y} S_Y - f_{E_Y} E_Y - f_{N_A} N_A - f_{S_A} S_A - f_{E_A} E_A
\]

Now, we divide each class with total population

To simplify the smoking behavior model analization, we use this following definitions \( n_Y = \frac{N_Y}{P} \), \( s_Y = \frac{S_Y}{P} \), \( e_Y = \frac{E_Y}{P} \), \( n_A = \frac{N_A}{P} \), \( s_A = \frac{S_A}{P} \), and \( e_A = \frac{E_A}{P} \). Then we get \( n_Y = \frac{P_Y}{P} - s_Y - e_Y \) and \( n_A = \frac{P_A}{P} - s_A - e_A \).

Next, we derivate differential equation system 1 to a proportional equation system by
substituting our new variables above. So we get

$$\frac{dS_Y}{dt} = \gamma Y_s A \frac{P_Y}{P_A + P_Y} + \delta N_s Y \frac{P_A}{P_A + P_Y} + (\gamma + \beta N) Y \frac{P_Y}{P_A + P_Y} - (\beta S + \mu Y + \tau + \alpha) Y + \omega Y e_Y - (\gamma Y + \delta N) Y \frac{A Y}{P_A + P_Y} - (\gamma Y + \beta N - \beta S) e^2_Y.$$

$$\frac{dE_Y}{dt} = \mu Y Y - (\beta E + \omega Y + \tau + \alpha) Y + \beta N e_Y \frac{P_Y}{P_A + P_Y} + \delta N e_Y \frac{P_A}{P_A + P_Y} + (\beta S - \beta N) Y e_Y$$

$$\frac{dP_Y}{dt} = \alpha P_A - (\beta + \tau + \alpha) Y \frac{P_Y}{P_A + P_Y} + (\beta + \mu - \beta - \tau) Y \frac{P_A}{P_A + P_Y} + \tau (1 - \rho) Y e_Y P_A + (\beta + \tau + \beta - \tau) e_Y P_Y - \tau (1 - \rho) s_{AY} P_Y$$

$$+ \tau (1 - \rho) s_{AY} P_A + (\beta + \tau - \tau) Y \frac{e_Y}{P_A + P_Y} + (\beta + \tau - \tau) e_Y P_Y + (\beta + \tau - \tau) e_Y P_Y - \beta S P_Y - \beta S Y^2.$$

$$\frac{dS_A}{dt} = (\gamma + \beta N) s_A \frac{P_A}{P_A + P_Y} + \gamma A s_Y \frac{P_A}{P_A + P_Y} - (\gamma + \beta + \beta N - \beta S) y_{AY}$$

$$- (\gamma + \delta N - \delta S) s_A e_Y - (\gamma + \delta N - \delta S) e_Y s_A + (\tau (1 - \rho) + \beta N) s_A \frac{P_Y}{P_A + P_Y} + (\beta + \tau + \beta + \tau) s_{AY} P_Y$$

$$+ (\beta + \tau - \tau) s_{AY} P_A + (\beta + \tau - \tau) s_{AY} P_Y + (\beta + \tau - \tau) s_{AY} P_Y - (\delta S + \mu A + \alpha) s_A - (\tau (1 - \rho) s^2_A) - (\gamma + \delta N - \delta S) s^2_A.$$

$$\frac{dE_A}{dt} = \mu A s_A + \tau (1 - \theta) Y e_Y - (\omega A + \delta E + \alpha) e_A + \beta N e_A \frac{P_Y}{P_A + P_Y} + (\beta S - \beta N) e_{AY}$$

$$+ (\beta E - \beta N) e_{AY} + \delta N e_A \frac{P_A}{P_A + P_Y} + (\delta S - \delta N) e_{AY} s_A + (\delta E - \delta N) e^2_A.$$

$$\frac{dP_A}{dt} = \tau p Y - \delta N P_A + \tau (1 - \rho) y_{AY} P_A + 2 \tau (1 - \rho) Y e_Y P_A + \tau (1 - \rho) Y e_Y P_Y$$

$$- (\delta S - \delta N) s_A P_A + (\delta N - \delta S - \delta (1 - \rho)) s_A P_Y - (\delta E - \delta N) e_A P_A - (\beta E - \beta N) e_{AY}$$

$$- (1 - \rho) s_{AY} P_A - (1 - \rho) s_{AY} P_Y - (1 - \rho) s_{AY} P_Y - (1 - \rho) s_{AY} P_Y - (1 - \rho) s_{AY} P_Y - \lambda P_A P_Y - \lambda P^2_A.$$

(2)

3. Analysis of Parameter Sensitivity

Based on the transition diagram 1, there are several factors that increase the number of smoker populations in Indonesia. The population in the youth smoker class ($S_Y$) can increase because of the displacement of the population of the non-smoker teenage class and population displacement from the former teenage smoker class, i.e. the teenager returns to smoking after deciding to stop smoking, this occurs because of his own desire to return to smoking, not because of interactions with smokers.

The population in the adult smoker class ($S_A$) can increase due to population movements from the adult non-smoker class, population displacement from adolescent non-smoker classes, population displacement from adolescent smoker class, population displacement from ex-teen smoker class and transfer of ex adult smoker population who returned to being a smoker.

In this section, we will analyze which factors are the most important so that we can take the most effective measures to control the smoking behavior. We analyze it with simulation in python program. The value of parameters that used in this paper are given in table 2.
Table 2. Table of Parameters Value

| Symbol | Value   | Source |
|--------|---------|--------|
| α      | 0.0159  | [8]    |
| β̂_N   | 0.0005  | Estimated |
| β̂_S   | 0.001   | Estimated |
| β̂_E   | 0.0006  | Estimated |
| δ̂_N   | 0.0007  | Estimated |
| δ̂_S   | 0.0014  | Estimated |
| δ̂_E   | 0.0009  | Estimated |
| γ̂_Y   | 0.4     | Estimated |
| γ̂_A   | 0.2     | Estimated |
| μ̂_Y   | 0.05    | Estimated |
| μ̂_A   | 0.06    | Estimated |
| ω̂_Y   | 0.01    | Estimated |
| ω̂_A   | 0.009   | Estimated |
| τ      | 0.0588  | Estimated |
| ρ      | 0.7     | Estimated |
| θ      | 0.7     | Estimated |
| η      | 0.4     | Estimated |
| λ      | 0.00000065 | Estimated |

Analysis of parameter sensitivity is done by changing the value of several parameters that increase the number of smokers in Indonesia. In this paper, the authors are interested in analyzing parameters that affect population changes from teenagers to adult. These parameters are ρ (the rate of young non-smokers still does not smoke until adult), θ (The rate of young smokers still smoke until adult), and η (the rate of young ex-smokers still does not smoke until adult).

Based on Figure 2 and 3, it is found that parameter ρ does not affect the number of adult smokers in Indonesia. Whereas, ρ affects the number of ex-smokers, the greater rho value, inversely proportional to the number of ex-smokers. This means that if the population of teenagers who do not smoke remain non-smoking until adulthood does not affect the number of adult smokers significantly or it can be said the number of adult smokers is constant, so that it can affect the number of ex-adult smokers who are decreasing.

Figure 2. Rho vs Adult Smokers

Figure 3. Rho vs Ex Adult Smokers
In Figure 4 and 5, it is found that parameter $\theta$ affects the number of adult smokers and ex-smokers in Indonesia. In 4, we can see that the greater $\theta$, the greater number of adult smokers. While, the number of ex-adult smokers is getting smaller. It means if the teenagers who smoke remain smoking until adulthood make the number of adult smokers increase, contrary it make the number of ex adult-smokers decreasing.

Next, Figure 6 and 7 show that parameter $\eta$ affects the number of adult smokers and ex-smokers in Indonesia. In 6, we can see that the greater $\eta$, the smaller number of adult smokers. While, the number of ex adult-smokers is getting bigger. This means if the teenagers who stop smoking remain do not smoke until adulthood make the number of adult smokers decreased, and it is good because the number of ex adult-smokers increasing.

Thus, it can be concluded that from the three parameters analyzed, the important parameters that affect the number of adult smokers are $\theta$ and $\eta$. The greater $\theta$, the greater number of adult smokers. Otherwise, the greater $\eta$, the smaller number of adult smokers. It means that we must make teenagers who smoke to not smoke again when they are adults, and teenagers who have quit smoking to remain do not smoke until they are adults.

4. Conclusions
In this paper, we investigate the mathematical model of smoking behavior by divide the population into six classes, that is young non-smokers, young smokers, ex young smokers, adult non-smokers, adult smokers, and ex adult smokers. After constructing the mathematical model, we analyze which factors that important in controlling smoking behavior. Through parameter sensitivity analysis with simulation in python program, we can get the conclusion
that maintaining teenage smokers who have stopped smoking still do not smoke until adulthood is more effective to make the number of adult smokers decrease. In addition, we must make teenagers who smoke when they were young to not smoke again when they are adults.

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