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Dynamical Analysis of Modified Mathematical Model of Social Media Addiction

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ABSTRACT

In this study, there is no division between addiction in the mild and severe stages. Therefore, it is necessary to divide the stages of addiction because the healing is clearly different. Therefore, in this study, a modified dynamic analysis of the Social Media addiction model is carried out to obtain a valid model that can be implemented in real life. This study aims to find the stability of changes in the Addicted variable which is divided into two, namely Social Media addiction in the mild stage (A_1) and Social Media addiction in the severe stage (A_2). There are six models that have been modified in this study, namely, individuals who do not have Social Media but are vulnerable to addiction (S), individuals who have Social Media but are not yet at the addiction stage (E), individuals infected with Social Media addiction in the mild stage (A_1), individuals infected with Social Media addiction in the severe stage (A_2), individuals who are recovering from Social Media addiction (R), individuals who are completely recovered from Social Media addiction (Q). The steps of dynamic analysis include determining the equilibrium point, analyzing the stability of the equilibrium point, finding the basic reproduction number, numerical simulation of all variables. The results showed that the population of individuals infected with Social Media addiction in the mild stage (A_1) was at a value of 1.6112 with t = 4 years while the population of individuals infected with Social Media addiction in the severe stage (A_2) was at a value of 36.542 with t = 4 years. This study provides information that the dynamic analysis carried out on the modified mathematical model of Social Media addiction shows a stable condition.

Keywords: Dynamic Analysis; Model Modification; Social Media Addiction Model

INTRODUCTION

Mathematical models are solutions to problems using differential equations with the aim of producing an equation that is easier to understand and easier to solve [1]. Mathematical models are divided into two types, namely dynamic models and static models. The model can be said to be dynamic if the condition variable u depends on the condition of the time variable t, while the model can be said to be static if the condition variable u does not depend on the condition of the time variable t [2]. A widely known mathematical model is the *SEIR (Suspected-Exposed-Infected-Recovery)* mathematical model which is a development of the *SIR (Suspected-Infected-Recovery)* mathematical model proposed by Kermack and McKendrick in 1927 [3]. From the mathematical model proposed by Kermack and McKendrick, in 2021 Alemneh and Alemu conducted research

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on social media addiction using the development of the *SEIR* mathematical model. The development of the resulting mathematical model is the *SEARQ* model which is divided into five groups, namely, individuals who do not yet have social media but are susceptible to addiction (*Susceptible*), individuals who have social media but are not susceptible to addiction (*Exposed*), individuals who are infected with addiction (*Exposed*), and individuals who are infected with addiction (*Addiction*), individuals who are recovering from social media addiction (*Recovery*), individuals who have recovered from social media addiction (*Quit*) [4].

Social Media is an application that presents short videos containing various content in the form of entertainment, knowledge, and current news. Social Media can cause its users to experience addiction which can be fatal for themselves and others [5]. Social Media addiction is a behavior of lack of self-control, neglect of social reality, and dependence between individuals and the Social Media application [6]. This Social Media addiction can occur if we use the Social Media application a lot at excessive times every day. In addition, if Social Media addiction is left untreated, the addicted person can contract Tourette's Syndrome. Tourette's Syndrome is a disease that causes the sufferer to make repetitive movements or utterances under their consciousness [7]. There have been many cases of Tourette's Syndrome caused by Social Media addiction which makes sufferers make movements from the videos they watch until they are carried over to the real world [8]. This disease can interfere with communication and can also cause mental disorders. Therefore, both addiction and Tourette Syndrome must receive special treatment so that it is not sustainable and can also create quality successors.

The modified model has six variables namely *Susceptible, Exposed,* $Addiction_1$, $Addiction_2$, *Recovery, Quit*. Susceptible is categorized as individuals who do not yet have Social Media but are vulnerable to addiction then Exposed is categorized as individuals who already have Social Media but have not reached the addiction stage. $Addiction_1$ is categorized as individuals who have been infected with Social Media addiction but are still at a mild stage, individuals who are categorized as addicted at a mild stage if they play Social Media within 4 to 6 hours a day [9]. $Addiction_2$ is categorized as individuals who are infected with severe Social Media addiction to experience Tourette Syndrome. These individuals can be categorized if they play Social Media for more than 6 hours a day and have started to show signs of Tourette Syndrome in their nerves which causes the individual to lose control of themselves. Recovery is an individual who is in the healing period, healing between mildly addicted and severely addicted individuals must be distinguished because they have different treatments from both. Quit is an individual who has completely recovered from Social Media addiction.

One of the benefits that can be taken from this research is to provide an understanding to the community that Social Media addiction that occurs in the surrounding environment is not something that should be allowed, because this addiction can cause disruption to the sufferer and also disruption to the surrounding people [10]. Moreover, if the addiction has entered a severe stage, causing the sufferer to experience Tourette Syndrome. Therefore, there needs to be healing done to reduce the number of Social Media addictions that occur. So with this research, people can be more sensitive to themselves and also the people around them to be able to manage their time and limit themselves in playing Social Media.

From the explanation above, the researcher modified the model and dynamic analysis to provide a solution to the differential equation of the mathematical model of Social Media addiction [11]. This research is expected to provide awareness to the public of the dangers of Social Media addiction which was previously considered trivial.

METHOD

Research Stages

The stages carried out to complete this research are divided into several types, namely as follows [12]:

a. Modification of Mathematical Model [13]

1. Form a compartment diagram with the modified variable Addiction (A) based on reference [14].
2. Define variables and parameter values associated with the compartment diagram
3. Set up differential equations in accordance with the compartment diagram that has been formed

b. Dynamic Analysis of Mathematical Model

1. Determine the equilibrium point of the mathematical model
2. Determine the stability analysis of the model
3. Determine the basic reproduction number (R_0)
4. Numerical simulation of Social Media addiction mathematical model in the form of graphs using Octave software

RESULTS AND DUSCUSSION

Modification of Mathematical Model

Modification of the mathematical model means an effort to change the variables and differential equations associated with the aim of getting a better solution and also more in accordance with the related problems. There are several steps taken in the modification of the mathematical model, namely:

- **Forming a Compartment Diagram Based on Reference [14]**

The following will show a compartment diagram that has been modified by adding the Addiction variable into two parts [15]:

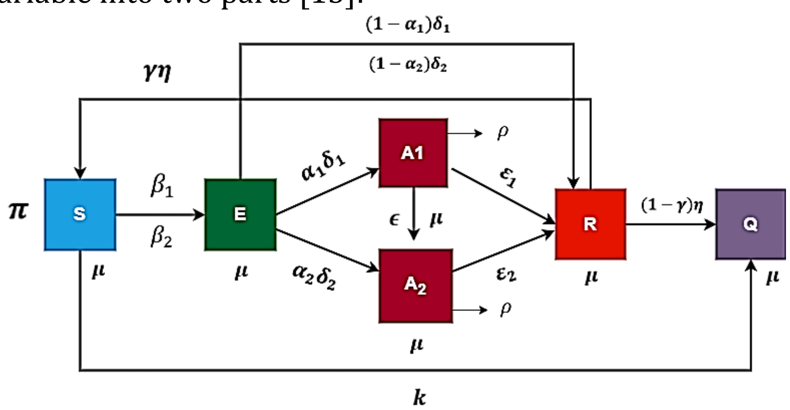

Figure 1. Compartment Diagram Modified Model of Social Media Addiction

- **Defining Variables and Parameters Values Associated with Compartment Diagrams**

Table 1. Variable Definitions

Variable	Descriptions
$S(t)$	Population of individuals susceptible to addiction Social Media
$E(t)$	Population of individuals who already Social Media
$A_1(t)$	Population of individuals exposed to Social Media addiction light category
$A_2(t)$	Population of individuals exposed to Social Media addiction severe category (*Tourette Syndrome)*
$R(t)$	Population of individuals who perform healing against Social Media addiction
$Q(t)$	Population of individuals who successfully recovered from addiction Social Media

Table 2. Parameters values of Social Media Addiction Model Modification

Parameters	Description	Value	Unit	Source
π	The rate of influence of the whole compartment	0.5	$\frac{1}{year}$	[14]
μ	Population rate natural death	0.25	$\frac{1}{year}$	[16]
β_1	Transmission rate of individuals who exposure to heavy Social Media addiction against the individuals who are prone to Social Media addiction	0.6	$\frac{1}{year}$	[17]
β_2	Transmission rate of individuals who exposure to heavy Social Media addiction against vulnerable individulas Social Media addiction	0.58	$\frac{1}{year}$	[18]
σ_1	Contact rate of Social Media addiction-prone individuals with Social Media addiction-exposed individuals is mild	0.5	$\frac{1}{year}$	[14]
σ_2	Contact rate of Social Media addiction-prone individuals with individuals exposed to severe Social Media addiction	0.22	$\frac{1}{year}$	[19]

Parameters	Description	Value	Unit	Source
α_1	Proportion of individuals who have Social Media admission to individuals exposed to mild Social Media addiction	0.7		[20]
α_2	Proportion of individuals who have Social Media admission to individuals exposed to severe Social Media addiction	0.242		[21]
ρ	Rate of death due to addiction	0.01	$\frac{1}{year}$	[22]
δ_1	Individuals who leave individuals who own Social Media	0.25	$\frac{1}{year}$	[23]
δ_2	Individuals who leave individuals who own Social Media	0.21	$\frac{1}{year}$	[18]
ϵ	The rate of moving from individuals exposed to mild addiction to individuals exposed to severe addiction	0.688	$\frac{1}{year}$	[24]
ε_1	Movement rate of mildly addicted individuals to recovering individuals	0.7	$\frac{1}{year}$	[25]
ε_2	Movement rate of individuals exposed to severe addiction to individuals in recovery	0.001	$\frac{1}{year}$	[18]
k	Rate of individuals exposed to addiction but not using Social Media or not affected by individuals addicted to Social Media	0.01	$\frac{1}{year}$	[26]
γ	Proportion of individuals who are in recovery but vulnerable to addiction	0.35		[26]
η	Individuals who come out of individuals who are doing healing	0.4	$\frac{1}{year}$	[26]

- **Set up Differential Equations in accordance with the Compartment Diagram that has been formed**

Based on the compartment diagram that has been formed, the resulting differential equation is:

$$\frac{dS}{dt} = \pi + \gamma\eta R - (\beta_1\sigma_1 A_1 + \beta_2\sigma_2 A_2)S - (k + \mu)S$$

$$\frac{dE}{dt} = (\beta_1\sigma_1 A_1 + \beta_2\sigma_2 A_2)S - (\delta_1 + \delta_2 + \mu)E$$

$$\frac{dA_1}{dt} = (\alpha_1\delta_1)E - [\epsilon + \varepsilon_1 + \rho + \mu]A_1$$

$$\frac{dA_2}{dt} = (\alpha_2\delta_2)E + \epsilon A_1 - [\varepsilon_2 + \rho + \mu]A_2$$

$$\frac{dR}{dt} = [(1 - \alpha_1)\delta_1 + (1 - \alpha_2)\delta_2]E + \varepsilon_1 A_1 + \varepsilon_2 A_2 - (\eta + \mu)R$$

$$\frac{dQ}{dt} = kS + (1 - \gamma)\eta R - \mu Q$$

Dynamic Analysis of Modified Mathematical Model of Social Media Addiction

- **Determining the Equilibrium Point of the Mathematical Model of Social Media Addiction**

1. Addiction-free equilibrium point

$$E_0 = (S^*, E^*, A_1^*, A_2^*, R^*, Q^*) = \left(\frac{\pi}{k}, 0,0,0, 0, \frac{\pi}{\mu}\right)$$

2. Addiction equilibrium point

$$S^* = \frac{\delta\varepsilon\rho}{\alpha\beta\rho + \alpha\sigma\epsilon + b\varepsilon\sigma}$$

$$E^* = \frac{((Q^*\alpha\beta\mu\rho + Q^*\alpha\mu\sigma\epsilon + Q^*b\varepsilon\mu\sigma - \delta\varepsilon k\rho)\varepsilon\rho\eta)}{((\alpha\beta\rho + \alpha\sigma\epsilon + b\varepsilon\sigma)(\alpha\phi\epsilon + \alpha\rho\tau + b\varepsilon\phi + \varepsilon\omega\rho)\theta)}$$

$$X^* = \frac{\alpha E^*}{\varepsilon}$$

$$Y^* = \frac{E^*(\alpha\epsilon + b\varepsilon)}{\varepsilon\rho}$$

$$R^* = \frac{E^*(\alpha\phi\epsilon + \alpha\rho\tau + b\varepsilon\phi + \varepsilon\omega\rho)}{\varepsilon\rho\eta}$$

- **Determining the stability Analysis of the Mathematical Model of Social Media Addiction**

1. Stability Analysis of Addiction-Free Equilibrium Point

$$\boldsymbol{J = 0.9999999444\lambda^6 + 3.779000916\lambda^5 + 2.270820850\lambda^4 - 1.95142873\lambda^3 - 2.30215383\lambda^2 - 0.7161585535\lambda - 0.07107378640}$$

A system is said to be stable if all the coefficients in the first column are positive. So it can be concluded that the equation is unstable because there is a negative sign in the first column. The calculation of the eigenvalue in the Jacobi matrix shows that the entire value is negative so it can be concluded that the eigenvalue is stable[27].

2. Stability Analysis of Addiction Equilirium Point

$$1.000000167\lambda^6 + 4.206597168\lambda^5 + 6.611368055\lambda^4 + 5.00707815\lambda^3 + 1.92389846\lambda^2 + 0.344866476\lambda + 0.02225824523$$

A system is said to be stable if all the coefficients in the first column are positive. So it can be concluded that the equation is stable because there is no negative sign in the first column. The calculation of the eigenvalue in the Jacobi matrix shows that the entire value is negative, so it can be concluded that the eigenvalue is stable [27].

- **Determining the Basic Reproduction Number (R_0)**

$$J_{(E_1)} = \begin{bmatrix} \frac{\partial E}{\partial E} & \frac{\partial E}{\partial A_1} & \frac{\partial E}{\partial A_2} \\ \frac{\partial A_1}{\partial E} & \frac{\partial A_1}{\partial A_1} & \frac{\partial A_1}{\partial A_2} \\ \frac{\partial A_2}{\partial E} & \frac{\partial A_2}{\partial A_1} & \frac{\partial A_2}{\partial A_2} \end{bmatrix} = \begin{bmatrix} -(\delta_1)-(\delta_2)-\mu & \beta_1\sigma_1\left(\frac{\pi}{k}\right) & \beta_2\sigma_2\left(\frac{\pi}{k}\right) \\ (\alpha_1\delta_1) & -\epsilon-\varepsilon_1-\rho-\mu & 0 \\ (\alpha_2\delta_2) & \epsilon & -\varepsilon_2-\rho-\mu \end{bmatrix}$$

1. Then the decomposition of the Jacobian matrix is performed[28]

$$F = \begin{pmatrix} 0 & \beta_1\sigma_1 S & \beta_2\sigma_2 S \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0 & \beta_1\sigma_1\left(\frac{\pi}{k}\right) & \beta_2\sigma_2\left(\frac{\pi}{k}\right) \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$V = \begin{pmatrix} -(\delta_1)-(\delta_2)-\mu & 0 & 0 \\ (\alpha_1\delta_1) & -\epsilon-\varepsilon_1-\rho-\mu & 0 \\ (\alpha_2\delta_2) & \epsilon & -\varepsilon_2-\rho-\mu \end{pmatrix}$$

Determining V^{-1}[29]

$$V^{-1} = \begin{pmatrix} -\frac{1}{\delta_1+\delta_2+\mu} & 0 & 0 \\ -\frac{\alpha_1\theta_1}{(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)} & -\frac{1}{\epsilon+\varepsilon_1+\rho+\mu} & 0 \\ -\frac{\mu\alpha_2\delta_2+\rho\alpha_2\delta_2+\epsilon\alpha_1\delta_1+\epsilon\alpha_2\delta_2+\alpha_2\delta_2\varepsilon_1}{(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)(\varepsilon_2+\rho+\mu)} & -\frac{\epsilon}{(\varepsilon_2+\rho+\mu)(\epsilon+\varepsilon_1+\rho+\mu)} & -\frac{1}{\varepsilon_2+\rho+\mu} \end{pmatrix}$$

2. $K = (F.V^{-1})$

$$= \begin{pmatrix} 0 & \beta_1\sigma_1\left(\frac{\pi}{k}\right) & \beta_2\sigma_2\left(\frac{\pi}{k}\right) \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}.$$

$$\begin{pmatrix} -\dfrac{1}{\delta_1+\delta_2+\mu} & 0 & 0 \\ -\dfrac{\alpha_1\theta_1}{(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)} & -\dfrac{1}{\epsilon+\varepsilon_1+\rho+\mu} & 0 \\ -\dfrac{\mu\alpha_2\delta_2+\rho\alpha_2\delta_2+\epsilon\alpha_1\delta_1+\epsilon\alpha_2\delta_2+\alpha_2\delta_2\varepsilon_1}{(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)(\varepsilon_2+\rho+\mu)} & -\dfrac{\epsilon}{(\varepsilon_2+\rho+\mu)(\epsilon+\varepsilon_1+\rho+\mu)} & -\dfrac{1}{\varepsilon_2+\rho+\mu} \end{pmatrix}$$

$$= \begin{pmatrix} -\frac{\pi\beta_1\sigma_1\alpha_1\delta_1}{(k+\mu)(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)}-\frac{\pi\beta_2\sigma_2(\mu\alpha_2\delta_2+\rho\alpha_2\delta_1+\epsilon\alpha_1\delta_1+\epsilon\alpha_2\delta_2+\alpha_2\delta_2\varepsilon_1)}{(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)(\varepsilon_2+\rho+\mu)} & -\frac{\pi\beta_1\sigma_1}{(k+\mu)(\epsilon+\varepsilon_1+\rho+\mu)}-\frac{\pi\beta_2\sigma_2\epsilon}{(k+\mu)(\mu+\rho+\epsilon+\varepsilon_2)(\epsilon+\varepsilon_1+\rho+\mu)} & -\frac{\pi\beta_2\sigma_2}{(k+\mu)(\mu+\rho+\varepsilon_2)} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$R_0 = \rho(K)$$

$$= \rho\begin{pmatrix} -\frac{\pi\beta_1\sigma_1\alpha_1\delta_1}{(k+\mu)(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)}-\frac{\pi\beta_2\sigma_2(\mu\alpha_2\delta_2+\rho\alpha_2\delta_1+\epsilon\alpha_1\delta_1+\epsilon\alpha_2\delta_2+\alpha_2\delta_2\varepsilon_1)}{(\epsilon+\varepsilon_1+\rho+\mu)(\delta_1+\delta_2+\mu)(\varepsilon_2+\rho+\mu)} & -\frac{\pi\beta_1\sigma_1}{(k+\mu)(\epsilon+\varepsilon_1+\rho+\mu)}-\frac{\pi\beta_2\sigma_2\epsilon}{(k+\mu)(\mu+\rho+\epsilon+\varepsilon_2)(\epsilon+\varepsilon_1+\rho+\mu)} & -\frac{\pi\beta_2\sigma_2}{(k+\mu)(\mu+\rho+\varepsilon_2)} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$= \frac{(\pi(\mu\alpha_1\beta_1\delta_1\sigma_1+\mu\alpha_2\beta_2\delta_2\sigma_2+\rho\alpha_1\beta_1\delta_1\sigma_1+\rho\alpha_2\beta_2\sigma_2+\epsilon\alpha_1\beta_2\delta_1\sigma_2+\epsilon\alpha_2\beta_2\delta_2\sigma_2+\alpha_1\beta_1\delta_1\varepsilon_2\sigma_1+\alpha_2\beta_2\delta_2\varepsilon_1\sigma_2)}{(k+\mu)(\mu+\rho+\varepsilon_2)(\mu+\rho+\epsilon+\varepsilon_1)(\mu+\delta_1+\delta_2)}$$

Using the parameter values in table 2, then

$$R_0 = 0.2503236655$$

Based on the calculation results found, it is proven that $R_0 < 1$, it can be concluded that the basic reproduction number (R_0) is locally asymptotically stable at the addiction-free equilibrium point [30].

- **Numerical Simulation of Social Media Addiction Mathematical Model in the Form of Graphs**

In this study, simulations were carried out to describe the spread of Social Media addiction using a modified mathematical model, namely the $\boldsymbol{S}, \boldsymbol{E}, \boldsymbol{A_1}, \boldsymbol{A_2}, \boldsymbol{R}, \boldsymbol{Q}$ model that has recovered from their Social Media addiction. In this simulation, the parameter values are in accordance with Tabel 2 so that the following graph can be obtained:

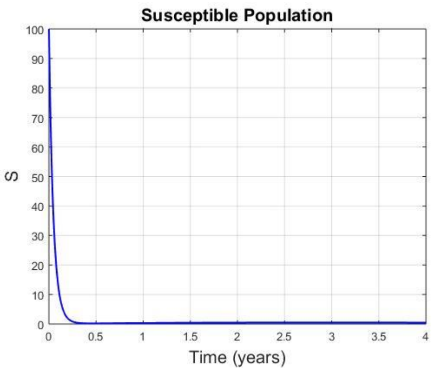

Figure 2. Simulation $S(t)$

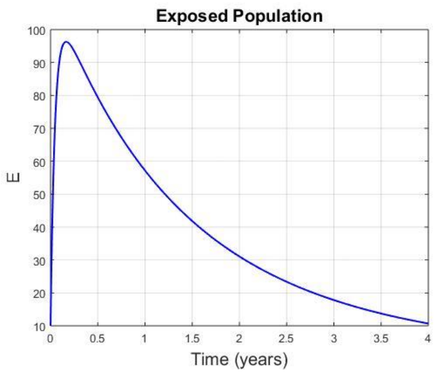

Figure 3. Simulation $E(t)$

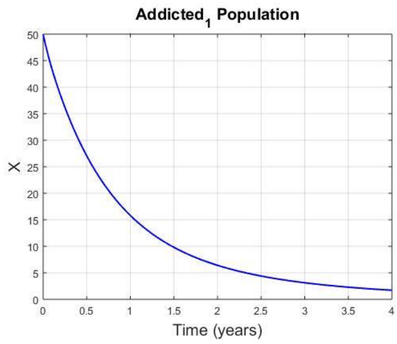

Figure 4. Simulation $A_1(t)$

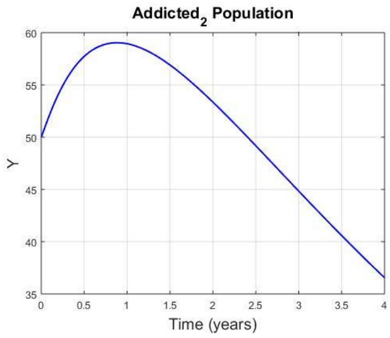

Figure 5. Simulation $A_2(t)$

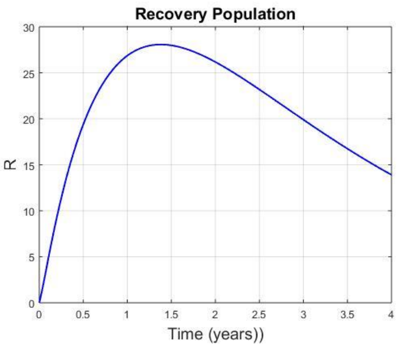

Figure 6. Simulation $R(t)$

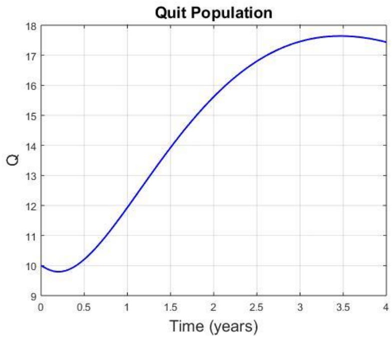

Figure 7. Simulation $Q(t)$

The modified model produces a decrease in the addiction rate which is closer to t = 0 until t = 4. The population of individuals who use Social Media has decreased and the addiction rate will even be zero over time in the population. This is in accordance with the Social Media addiction-free equilibrium point obtained, namely: $E_0 = (S, E, A_1, A_2, R, Q) = \left(\frac{\pi}{k}, 0,0,0,0, \frac{\pi}{\mu}\right)$ with $R_0 = 0.2503236655 < 1$. Therefore, Social Media addiction will slowly reduce and will disappear with time.

CONCLUSIONS

Based on the model modifications and dynamic analysis calculations above, it can be concluded that dividing Addiction into two parts as light Social Media addiction (A_1) and heavy Social Media addiction (A_2) provides dynamic calculation results that are more stable compared to the unmodified model. The modified model produces a more stable decline in the addicted population. This causes the population of individuals who use Social Media to also decrease so that the number of Social Media addictions over time will decrease and then disappear in the population.

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