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EFFECT OF AWARENESS PROGRAMS BY MEDIA ON THE TRANSMISSION MODEL OF PNEUMONIA IN THAILAND

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Abstract

Pneumonia is the most important cause of child death in Thailand. Media is the power source in the knowledge transfer and dissemination process. This study explores the effect of awareness programs by media on the transmission model of pneumonia in Thailand. This dynamical model is analyzed using a standard dynamical modeling method. The stability of the model was determined by using Routh-Hurwitz criteria. In this paper, the disease free and endemic states have been found. To determine the basic reproductive number (R_0) which is the threshold parameter, if $R_0 < 1$, then the disease free equilibrium point is locally asymptotically stable. The result shows that the awareness programs by media significantly cause the reduction in transmission and infection of pneumonia in Thailand. So, the media may be another option to prevent and control the disease.

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I. Introduction

Pneumonia is the illness killing over 1.8 million children under 5 years old around the world every year especially in developing countries. WHO and UNICEF have paid attention to this illness and developed the Global Action Plan for the prevention and control of Pneumonia (GAPP). The objective of GAPP is to increase awareness of pneumonia as a major cause of child death and take effective action to deal with the problem [1, 2]. In Thailand, pneumonia has not been significantly considered in action. In 2012, the figure from the Ministry of Public Health of Thailand showed that there are 194,094 children under 5 year old suffering pneumonia, 1,255 died from this disease. The trend of the number is increasing continually [3].

The mathematical model has been used to understand and analyze a spread of infectious diseases. It is very useful tool to govern the spread of infectious diseases. The analytical solution, numerical solution and simulation are ones of various mathematical methods used to analyze the harmful diseases without researching in the real environment that may infect the researchers [4-6]. Several researches mainly studied on the interactions between susceptible and infective but there are other factors, such as media coverage, vaccination or migration of population, which also affect the spread of infectious diseases.

Nowadays, media have become powerful tool to promote and share information. News, Internet, television, magazine or social media are part of daily activities that people can access rapidly and easily. Therefore, the awareness program of targeted diseases can be shared via the modern media to the population so that it can make people more aware of and prevent the spread of infection. There were several researches on investigation of the role of media to infectious diseases. For example, in [7] and [8], the authors used the SIS infection model and found out that increasing media coverage causes a lower infection rate. In 2009, the authors in [9] develop and study a mathematical model where the host population is less susceptible due to the spread of awareness. Also, in [10], the authors using a statistical analysis showed that there is a connection between influenza vaccination 1999-2001

and media reporting, specifically headlines on flu-related issues. Moreover, in [11], the authors studied the effect of awareness programs on the spreading of infectious disease and they found that an awareness program has a significant effect on disease control.

To model and analyze the spread of disease, there are many statistical models such as SIS, SIVR or SIR model that has been applied in the researches. For example, in [7] and [8], the authors used the SIS infection model while in [12] the authors developed and analyzed a nonlinear SIS mathematical model in the presence of a media awareness program. In [13], the authors developed a SIVR (Susceptible-Infected-Vaccinated-Recovered) epidemic model to study the effect of media broadcasting on the spread and control over an influenza outbreak while in [14] the authors studied an SIR Filippov epidemic model with media coverage.

In this research, the SIR model has been used to analyze the spread of pneumonia by considering effect of awareness program to the reduction of transmission level of this disease. So, the suitable awareness program through media may be another option to prevent and control the pneumonia in Thailand.

II. Mathematical Model

As the SIR model (Susceptible-Infectious-Recovered), the effect of awareness program is considered to acknowledge from content of media the reduction of transmission level of this disease, then the susceptible class is separated to susceptible class that has no disease information and the class that has disease information. And both classes can be infective class. The structure of transfer diagram of model system is applied from [15] to suitable with the pneumonia in Thailand.

The population is assumed that the human population is constant and divided into five compartments as follows: S, V, I, R, S_M and M represent the number of susceptible class, vaccination class, infective class, recovered class, susceptible class acknowledge from content of media and the cumulative density of the awareness programs driven by media in that region

at time *t*, respectively. The transmission dynamics of the pneumonia in Thailand are described by the compartment diagram, Figure 1.

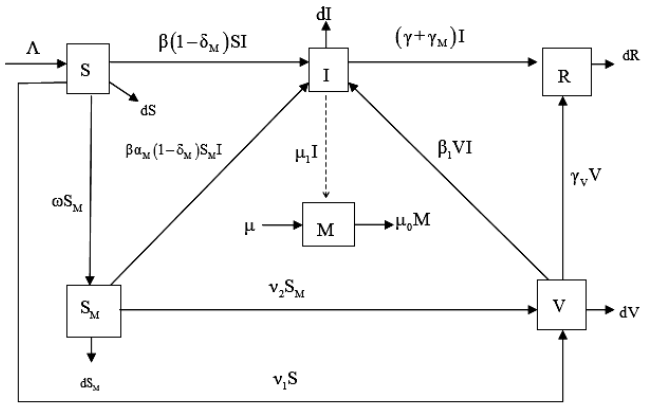


Figure 1. Conceptual model of the transmission of pneumonia in Thailand.

The transmission dynamics of the disease are described by the following systems of nonlinear ordinary differential equations:

$$\frac{dS}{dt} = \Lambda - [\beta(1-\delta_M)I + \omega M + \nu_1 + d]S, \tag{1}$$

$$\frac{dS_M}{dt} = \omega S_M - [\beta\alpha_M(1-\delta_M)I + \nu_2 + d]S_M, \tag{2}$$

$$\frac{dV}{dt} = \nu_1 S + \nu_2 S_M - (\beta_1 I + \gamma_v + d)V, \tag{3}$$

$$\frac{dI}{dt} = [\beta(1-\delta_M)(S + \alpha_M S_M) + \beta_1 V - (\gamma + \gamma_M + d)]I, \tag{4}$$

$$\frac{dR}{dt} = \gamma_v V + (\gamma + \gamma_M)I - (\sigma + d)R, \tag{5}$$

$$\frac{dM}{dt} = \mu + \mu_1 I - \mu_0 M. \tag{6}$$

Since the population of $N = S + S_M + V + I + R$, where N is a number of human population; Λ denotes the recruitment rate of human; d the natural mortality rate; β the probability of pneumonia transmit of susceptible, β_1 the

dissemination rate of awareness among susceptibles due to media awareness programs; ω the probability of susceptible class acknowledge from content of media; δ_M the probability of infectives; $1-\delta_M$ the probability of infectives are interacting with susceptibles; α_M the probability of aware susceptible class interacts with infectives; ν_1 the rate at which susceptibles begin the vaccination process; ν_2 the rate at which susceptible class acknowledge from content of media begin the vaccination process; γ the recovery rate of human; γ_ν the rate vaccination class immunity and move into recovered class; γ_M the probability of recovery rate driven by media awareness programs; μ_1 the rate constant influenced by number of infectives; μ_0 the natural decay rate constant of media coverage/awareness programs; μ the rate constant corresponding to regular media coverage, respectively.

III. Equilibrium Analysis

To begin with the disease free equilibrium, the endemic equilibrium and the basic reproductive number, respectively.

A. The disease free equilibrium (DFE)

The system has two equilibrium points; a disease free equilibrium point and an endemic equilibrium point,

$$E_0(S, S_M, V, I, M)$$

$$= E_0\left(\frac{\mu_0\Lambda}{\omega\mu+\mu_0(\nu_1+d)}, \frac{\omega\mu\mu_0\Lambda}{\mu_0(\omega\mu+\mu_0(\nu_1+d))(\nu_2+d)}, \frac{\nu_1\mu_0\Lambda Q_5+\nu_2\omega\mu\mu_0\Lambda Q_2}{\beta\alpha_M\mu_0(1-\delta_M)\mu_0(\nu_2+d)Q_1Q_2}, 0, \frac{\mu}{\mu_0}\right).$$

B. The disease endemic equilibrium (DEE)

Consider $H_1I^{3*}+H_2I^{2*}+H_3I^*+H_4>0$, we get

$$S^* = \frac{\mu_0\Lambda}{[\mu_0\beta(1-\delta_M)+\omega\mu_1]I^*+\omega\mu+\mu_0(\nu_1+d)},$$

$$S_M^* = \frac{\omega\mu\mu_0\Lambda + \omega\mu_0\mu_1\Lambda I^*}{Q_3 I^{2*} + Q_4 I^* + Q_5},$$

$$V^* = \frac{Q_6 I^{2*} + Q_7 I^* + Q_8}{(Q_1 I^* + Q_2)(Q_3 I^{2*} + Q_4 I^* + Q_5)},$$

$$M^* = \frac{\mu + \mu_1 I^*}{\mu_0}.$$

Thus, the endemic equilibrium is

$$E_1(S^*, S_M^*, V^*, I^*, M^*)$$

$$= E_1\left(\begin{array}{c} \dfrac{\mu_0\Lambda}{[\mu_0\beta(1-\delta_M) + \omega\mu_1]I^* + \omega\mu + \mu_0(\nu_1 + d)}, \\ \dfrac{\omega\mu\mu_0\Lambda + \omega\mu_0\mu_1\Lambda I^*}{Q_3 I^{2*} + Q_4 I^* + Q_5}, \\ \dfrac{Q_6 I^{2*} + Q_7 I^* + Q_8}{(Q_1 I^* + Q_2)(Q_3 I^{2*} + Q_4 I^* + Q_5)}, I^*, \dfrac{\mu + \mu_1 I^*}{\mu_0} \end{array}\right).$$

C. Basic reproductive number

The basic reproductive number is obtained by the next generation matrix. By [15] we start with

$$\frac{dX}{dt} = F(x) - V(x),$$

where F is the matrix of new infectious and V is the matrix of the transfers between the compartments in the infective equations. Therefore,

$$F = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \beta(1-\delta_M)(S + \alpha_M S_M)I + \beta_1 VI \\ 0 \end{bmatrix},$$

$$V = \begin{bmatrix} [\beta(1-\delta_M)I + \lambda M + \nu_1 + d]S - \Lambda \\ [\beta\alpha_M(1-\delta_M)I + \nu_2 + d]S_M - \omega SM \\ (\beta_1 I + \gamma_v + d)V - \nu_1 S - \nu_2 S_M \\ (\gamma + \gamma_M + d)I \\ \mu_0 M - \mu - \mu_1 I \end{bmatrix}.$$

The basic reproductive number, R_0, is the threshold for indicating the degree of epidemiology of the disease. It can be determined by noting that $\rho(FV^{-1})$, the Jacobian matrices are

$$F = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \beta(1-\delta_M)I & \beta(1-\delta_M)\alpha_M I & \beta_1 I & \beta(1-\delta_M)S + \beta(1-\delta_M)\alpha_M S_M + \beta_1 V & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

and

$$V = \begin{bmatrix} \beta(1-\delta_M)I + \omega M + \nu_1 + d & 0 & 0 & \beta(1-\delta_M)S & 0 \\ -\omega M & \beta\alpha_M(1-\delta_M)I + \nu_2 + d & 0 & \beta\alpha_M(1-\delta_M)S_M & -\omega S \\ -\nu_1 & -\nu_2 & \beta_1 I + \gamma_v + d & \beta_1 V & 0 \\ 0 & 0 & 0 & \gamma + \gamma_M + d & 0 \\ 0 & 0 & 0 & -\mu_1 & \mu_0 \end{bmatrix}.$$

This leads to

$$FV^{-1} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \dfrac{\beta(1-\delta_M)S + \beta(1-\delta_M)\alpha_M S_M + \beta_1 V}{(\gamma + \gamma_M + d)} & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

then

$$\rho(FV^{-1}) = \max\left\{0, \frac{\beta(1-\delta_M)S + \beta(1-\delta_M)\alpha_M S_M + \beta_1 V}{\gamma + \gamma_M + d}\right\}.$$

Hence, basic reproductive number $(\Re_0)$ is

$$\Re_0 = \sqrt{\frac{\beta(1-\delta_M)S + \beta(1-\delta_M)\alpha_M S_M + \beta_1 V}{\gamma + \gamma_M + d}}.$$

IV. Stability Analysis

The local stability of an equilibrium point is determined from the Jacobian matrix of the ordinary differential equation evaluated at E_0,

$$J_0 = \begin{bmatrix} -(\omega M + \nu_1 + d) & 0 & 0 & -\beta(1-\delta_M)S & -\omega S \\ \omega M & -(\nu_2 + d) & 0 & -\beta\alpha_M(1-\delta_M)S_M & \omega S \\ \nu_1 & \nu_2 & -(\gamma_v + d) & -\beta_1 V & 0 \\ 0 & 0 & 0 & \beta(1-\delta_M)(S+\alpha_M S_M) + \beta_1 V - (\gamma + \gamma_M + d) & 0 \\ 0 & 0 & 0 & \mu_1 & -\mu_0 \end{bmatrix}.$$

The eigenvalues value of are obtained by solving $\det(J_0 - \lambda I) = 0$. So, the characteristic equation is

$$(-(\gamma_v + d) - \lambda)(-(\nu_2 + d) - \lambda)(-(\omega M + \nu_1 + d) - \lambda)$$

$$(\beta(1-\delta_M)(S + \alpha_M S_M) + \beta_1 V - (\gamma + \gamma_M + d) - \lambda)(-\mu_0 - \lambda) = 0,$$

where

$$\lambda_1 = -(\gamma_v + d),$$

$$\lambda_2 = -(\nu_2 + d),$$

$$\lambda_3 = -(\omega M + \nu_1 + d),$$

$$\lambda_4 = -(\gamma + \gamma_M + d) + \beta(1-\delta_M)(S + \alpha_M S_M) + \beta_1 V,$$

$$\lambda_5 = -\mu_0.$$

Next, the stability of the endemic equilibrium point E_1 is considered so the eigenvalue of Jacobian matrix at E_1 is determined, which is

$$J_1 = \begin{bmatrix} -B_1 & 0 & 0 & -B_6 & -\omega S \\ \omega M & -B_3 & 0 & -B_7 & \omega S \\ \nu_1 & \nu_2 & -B_5 & -\beta_1 V & 0 \\ B_2 & B_4 & \beta_1 I & -B_8 & 0 \\ 0 & 0 & 0 & \mu_1 & -\mu_0 \end{bmatrix},$$

where

$$B_1 = \beta(1-\delta_M)I + \omega M + \nu_1 + d,$$

$$B_2 = \beta(1-\delta_M)I,$$

$$B_3 = \beta\alpha_M(1-\delta_M)I + \nu_2 + d,$$

$$B_4 = \beta\alpha_M(1-\delta_M)I,$$

$$B_5 = \beta_1 I + \gamma_v + d,$$

$$B_6 = \beta(1-\delta_M)S,$$

$$B_7 = \beta\alpha_M(1-\delta_M)S_M,$$

$$B_8 = \gamma + \gamma_M + d - \beta(1-\delta_M)(S + \alpha_M S_M) - \beta_1 V.$$

The eigenvalues value of are obtained by solving $\det(J_0 - \lambda I) = 0$. So, the characteristic equation is

$$I^5 + C_1 I^4 + C_2 I^3 + C_3 I^2 + C_4 I + C_5 = 0,$$

where

$$C_1 = B_1 + B_3 + B_5 + B_8 + \mu_0,$$

$$C_2 = \mu_0(B_1 + B_3 + B_5 + B_8) + B_9,$$

$$C_3 = B_{10} + \mu_0 B_9 - \mu_1 \omega S^*(B_4 + B_2),$$

$$C_4 = ((\mu_0 B_{10} + B_{11}) + (\nu_1 B_1 - \nu_2)\beta_1 I$$

$$- B_4(B_5 - \omega M^* - B_1) - B_2(B_5 - B_3))\mu_1 \omega S^*,$$

$$C_5 = \mu_0 B_{11} + \mu_1 \omega S^*(B_5(\omega B_4 M^* + B_2 B_3 - B_1 B_4) + (\nu_1 B + \nu_2 \omega M - \nu_2)\beta_1 I).$$

By Routh-Hurwitz criteria [16], equilibrium points are locally asymptotically stable if all conditions are satisfied:

(1) $C_i > 0$; $i = 1, 2, 3, 4, 5$,

(2) $C_1 C_2 C_3 > C_3^2 + C_1^2 C_4$,

(3) $(C_1 C_4 - C_5)(C_1 C_2 C_3 - C_3^2 - C_1^2 C_4) > C_5(C_1 C_4 - C_3)^2 + C_1 C_5^2$.

V. Numerical Simulation

In this section, several scenarios using demonstrated data were used to validate the performance of the mathematical models using the set of estimated parameter values given in Table 1. The parameters were obtained from literatures of [15] and [17], the parameters that were not available in literatures were estimated. The software used for computation is Maple.

First, the stability of disease free state using set of parameter values of study the system of nonlinear ordinary differential equations (1)-(6) is considered. The eigenvalues corresponding to the equilibrium point E_0 and basic reproductive number are following:

$$\lambda_1 = -80.0010456, \quad \lambda_2 = -0.01333719,$$

$$\lambda_3 = -0.10045662, \quad \lambda_4 = -0.14290281,$$

$$\lambda_5 = -0.001,$$

$$\Re_0 = 0.954920548 < 1.$$

Since all eigenvalues corresponding to E_0 is negative, thus E_0 is locally asymptotically stable and basic reproductive number less than 1. Further, to illustrate the stability of endemic free state, shown that the results are:

$$\lambda_1 = -0.00004566, \quad \lambda_2 = -0.00551832,$$

$$\lambda_3 = -0.00100007, \quad \lambda_4 = -0.08232734,$$

$$\lambda_5 = -0.14293218,$$

$$\Re_0 = 1.318312134 > 1.$$

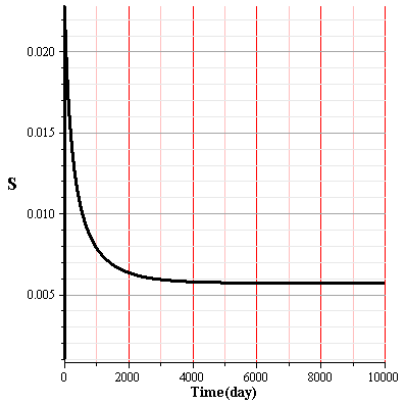
The same, all eigenvalues are negative and basic reproductive number is greater than 1, the equilibrium state will be the endemic state, E_1. In the details, Figures 2-3 can show the results of this simulation study as follows:

Table 1. Parameter values used in the numerical simulation at disease free state

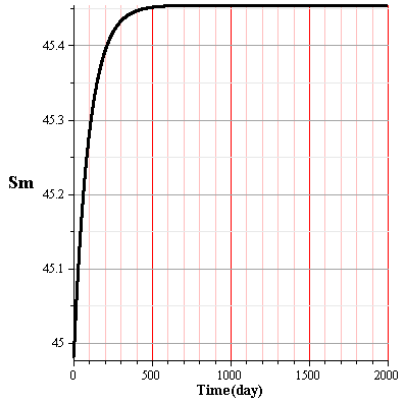
Parameters	Description	Values
N	Number of human population	10000
Λ	The recruitment rate of human	0.456621
d	The natural mortality rate	0.0000456
β	The probability of pneumonia transmit of susceptible	0.025
β_1	The probability of pneumonia transmit of vaccination class	0.0001
ω	The probability of susceptible class acknowledge from content of media	0.1/0.0001
δ_M	The probability of infectives	0.8
$1-\delta_M$	The probability of infectives are interacting with susceptibles	0.2
α_M	The probability of aware susceptible class interacts with infectives	0.6
ν_1	The rate at which susceptibles begin the vaccination process	0.001
ν_2	The rate at which susceptible class acknowledge from content of media begin the vaccination process	0.01
γ	The recovery rate of human	0.05
γ_v	The rate vaccination class immunity and move into recovered class	0.1428571

γ_M	The probability of recovery rate driven by media awareness programs	0.1
μ_1	The rate constant influenced by number of infectives	0.001
μ_0	The natural decay rate constant of media coverage/awareness programs	0.001
μ	The rate constant corresponding to regular media coverage	0.001

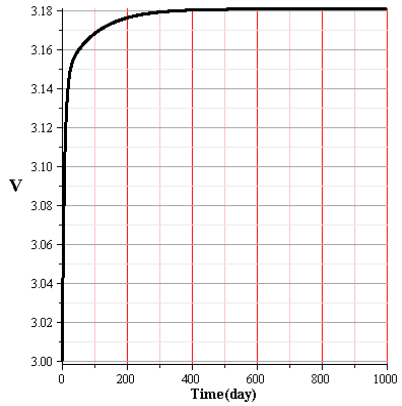
The disease free equilibrium (E_0) will be local asymptotically stable, as follows:



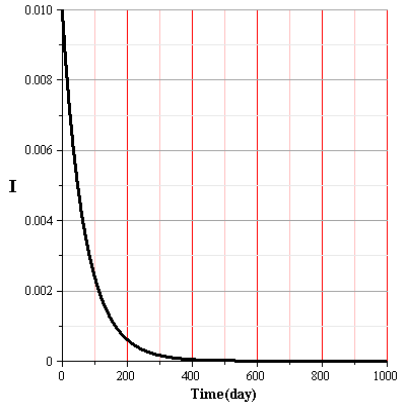
(a) Time series of susceptible class



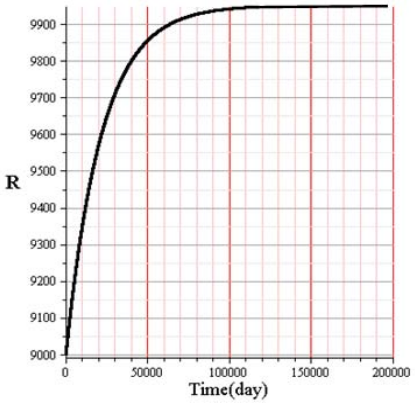
(b) Time series of susceptible class acknowledge from content of media



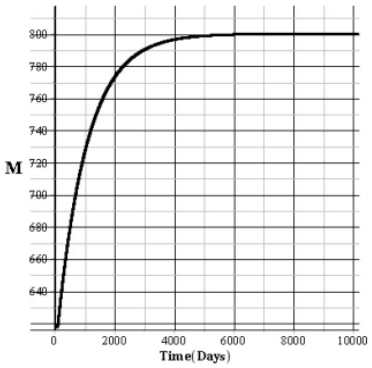
(c) Time series of vaccination class



(d) Time series of infective class



(e) Time series of recovered class



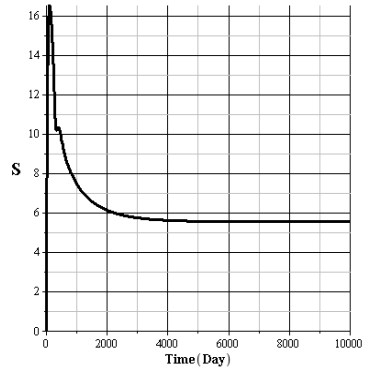
(f) Time series of the cumulative density of the awareness programs driven by media

Figure 2. Time series of susceptible class, susceptible class acknowledge from content of media, vaccination class, infective class, recovered class and the cumulative density of the awareness programs driven by media, respectively.

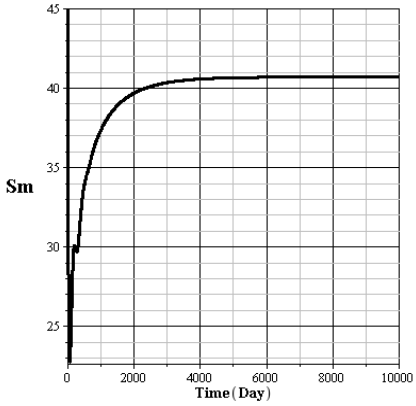
From Figure 2, when the time increases long enough, the graph will converge to $E_0(S,\ S_m,\ V,\ I,\ R,\ M)$, where

$$E_0(S,\ S_m,\ V,\ I,\ R,\ M) = E_0(0.0057,\ 45.4539,\ 3.1808,\ 0,\ 9951.3595,\ 800).$$

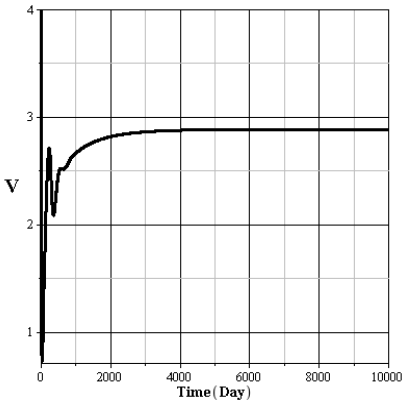
When considering the stability of the system at the disease free equilibrium, the eigenvalue of all specific parameters will be negative. This condition conforms to Routh-Hurwitz criteria that the disease free equilibrium will be local asymptotically stable.



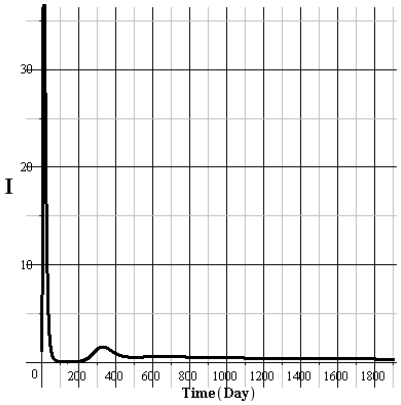
(a) Time series of susceptible class



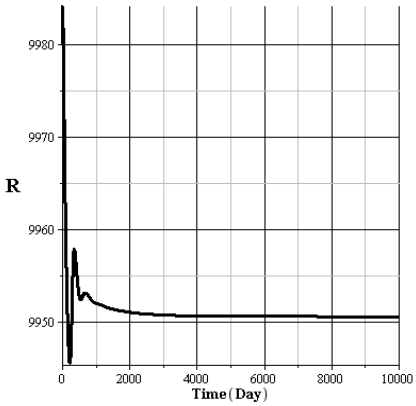
(b) Time series of susceptible class acknowledge from content of media



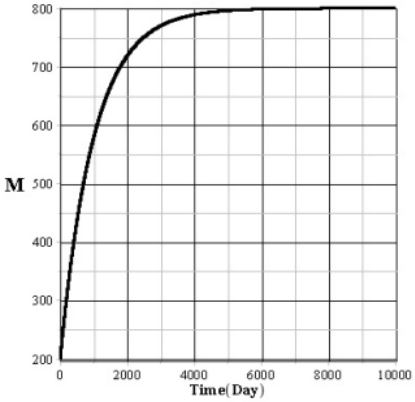
(c) Time series of vaccination class



(d) Time series of infective class



(e) Time series of recovered class



(f) Time series of the cumulative density of the awareness programs driven by media

Figure 3. Time series of susceptible class, susceptible class acknowledge from content of media, vaccination class, infective class, recovered class and the cumulative density of the awareness programs driven by media, respectively.

From Figure 3, when the time increases long enough, the graph will converge to $E_0(S, S_m, V, I, R, M)$, where

$$E_1(S^*, S_m^*, V^*, I^*, R^*, M^*)$$

$$= E_1(5.5363, 40.6919, 0.2808, 9950.6053, 800).$$

When considering the stability of the system at the disease free equilibrium, the eigenvalue of all specific parameters will be negative. This condition conforms to Routh-Hurwitz criteria that the disease free equilibrium will be local asymptotically stable.

VI. Conclusion

The objective of this research is to analyze the spread of pneumonia by considering effect of awareness program to the reduction of transmission level of this disease. For numerical illustration, it starts from analytical solution, numerical solution and simulation. The results are summarized in Figures 2-3 by presenting the important values and the model system shown that the disease free equilibrium is stable until, the basic reproduction number, $R_0 < 1$. The disease free equilibrium becomes unstable for $R_0 > 1$, which leads to the existence of an endemic equilibrium.

The research studies when $\omega = 0.1$ (the probability of susceptible class acknowledge from content of media). The result shows $\Re_0 = 0.954920548 < 1$ so if the media has been broadcasted for more than 0.1, pneumonia can be controlled. If the parameter $\omega = 0.0001$ affects the spread of pneumonia, the more value of ω is, the susceptible who get more information from media, the result shows $\Re_0 < 1$ and it means the spread of pneumonia is under control but if $\Re_0 > 1$ there will be spread of pneumonia when the less value of ω is. These results are similar to the research of [7, 8]. Both researches studied the effect of media to the spread of disease. The researchers also found that if the basic reproduction number is greater than 1. It means that the effect of media is quite high. Therefore it is clearly shown that the awareness programs by media significantly cause the reduction in transmission and infection of pneumonia in Thailand.

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