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Research Article

The effects of online game addiction therapeutic camp on stability of online game addiction model for children and youth in Thailand

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Abstract - Online game addiction is one of the major issues that affects many aspects of child and youth development such as physical development, intelligence, meditation and violent behavior. Due to the fact that there is an increase in the number of addicted gamers every year, this research explored the effects of a therapeutic camp for children and youth who are addicted to online gaming and a support from family to heal, care and give attention to children more closely by constructing and analyzing mathematical model in the form of $PATQ_tQ_p$ model. The model is studied theoretically and numerically. The basic reproduction number R_0 and its sensitivity is calculated. Optimal control model is also constructed. A mathematical program is also used to explore the impact of some parameters on dynamics in specific cases. This is to find some approaches to control the epidemic or reduce number of addicted gamers in Thailand.

Keywords: Online game addiction, therapeutic camp, numerical analysis, optimal control

1. Introduction

The internet has been broadened since 1990s and has greatly influenced our daily life, not only in education and business, but also in healthcare and the entertainment industry. With the growth of the internet and its variety, people around the world spend a lot of time using the internet every day. Over the past two decades, the concept of internet addiction has grown in terms of its acceptance as a new and often unrecognized clinical disorder that impacts a user's ability to control online use to the extent that it can cause relational, occupational, and social problems and most cases require treatment (Young, 2007). Online gaming is another popular form of entertainment through internet usage and has become increasingly popular. Excessive gaming has now been identified as a specific subtype of internet addiction (Block, 2008). Reports show that internet addiction, in particular an online game addiction, has become a serious public health concern in many countries such as Taiwan (Lee, 2007), Korea (Hur, 2006) and Thailand (Wanpen, 2016).

A large number of studies show the negative consequences of internet and online game addiction together with the co-occurrence with mental health problems, physical health problems and academic failure (Grant *et al*., 2010; Cao *et al*., 2011; Salmon *et al*., 2011; Carli *et al*., 2013). In extreme cases of gamers, these can include sacrificing work, education, hobbies, socializing, time with family, and sleep, decreased academic achievement, aggressive/oppositional behavior, maladaptive cognitions and suicidal ideation (Griffiths *et al*., 2012). Therefore, the prevention and treatment of those who are addicted to online gaming is essential.

As for treatment, the evidence shows that in Europe, the first clinic for game addiction was set up in Amsterdam (Videogame Addiction, 2006). The clinic uses therapy groups, consisting of psychologists, psychiatrists, and therapists, to identify replacement activities to help patients forget gaming (Zhan *et al.,* 2012) During the treatment period, patients are not allowed to access computer games. In addition, similar online game addiction clinics have been established in ChinaJapan, and the United States and Zhan *et al*. (2012) suggested that more national governments should move toward establishing clinics dedicated to treating online game addicts. In Thailand, a few therapeutic camps for those addicted to online gaming have been set up recently e.g. the camp under a project called DigitalDekD organised by Thai Health Promotion Foundation. Further, some media organisations have promoted a series of TV programs to show how one can bring their children who are game addicted back. This series can be found on Youtube: Siriraj HealthyGamer Channel under the program called Let Me Grow.

Another aspect that we focus in this study is the family factor. Due to the fact that young people are primarily preoccupied with online gaming, their parents may have a major role to play in the process of prevention and rehabilitation (Karapetsas *et al*., 2014). The work by (Wu *et a*l., 2016) shows that parents can play a protective role

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in their response to adolescent behavior, and the importance of family functionality and parenting approaches should not be underestimated. Family-based prevention of internet addiction should be implemented to deal with this globally problematic issue. Using these important facts presented above, we construct online game addiction mathematical modeling to investigate the effects of therapeutic camps on the number of online game addicts. The model is analyzed both theoretically and numerically with the condition of its stability. Finally, we expand our model by adding two optimal controls i.e. therapeutic camp control and the family understanding control to seek for potential strategies to reduce an overall online game addiction in Thailand.

2. Model formulation

The model in this study is modified from the work by Sookpiam *et al*. (2018) involving the effect of a therapeutic camp on online game addiction for children and youth in Thailand. The addicted gamers are assumed to be transferred to the therapeutic camp group, and after the camp, they will either temporarily or permanently quit playing games. The schematic diagram of this model is shown below.

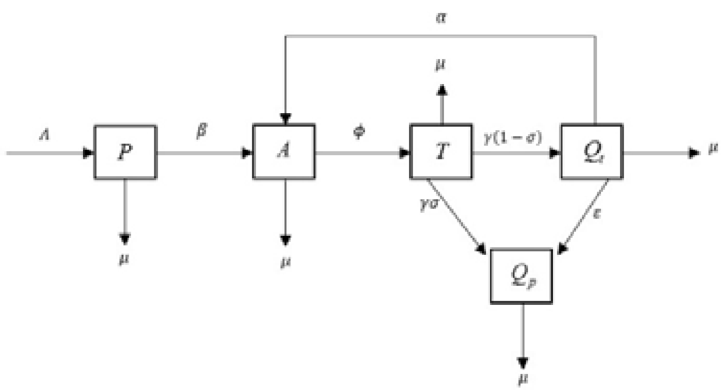

Figure 1: A schematic diagram of online game addiction with therapeutic camp dynamics.

The corresponding differential equations are

$$\frac{dP}{dt} = \Lambda - \beta PA - \mu P \tag{1}$$

$$\frac{dA}{dt} = \beta PA + \alpha Q_t - (\mu + \phi)A \tag{2}$$

$$\frac{dT}{dt} = \phi A - (\mu + \gamma)T \tag{3}$$

$$\frac{dQ_t}{dt} = \gamma(1-\sigma)T - (\mu + \alpha + \varepsilon)Q_t \tag{4}$$

$$\frac{dQ_p}{dt} = \gamma\sigma T + \varepsilon Q_t - \mu Q_p. \tag{5}$$

Notation:

P is the number of potential addicted gamers, A is the number of addicted gamers, T is the number of addicted gamers who get treatment with therapeutic camp, Q_t is the number of addicted gamers who temporarily quit playing games, Q_p is the number of addicted gamers who permanently quit playing games, Λ is the recruitment rate of human population in Thailand, β is the contact rate between potential addicted gamers and addicted gamers, ϕ is the rate of addicted gamers who go for treatment at the therapeutic camp, α is the rate of addicted gamers who temporarily quit playing games but revert back to be addicted gamers, γ is the rate of quitting playing games of addicted gamers who get treatment with therapeutic camp, σ is the fraction of addicted gamers who get treatment with a therapeutic camp and permanently quit playing games, 1-σ is the remaining fraction of addicted gamers who get treatment with therapeutic camp and temporarily quit playing games, μ is the natural death rate of human population in Thailand.

2.1 Boundary of solution

In this section, we determine the boundary of the system of equations (1) - (5). We have $N_t = \frac{\Lambda}{\mu} - \left[\frac{\Lambda}{\mu} - N_0\right]e^{-\mu t}$, where $N_t = P + A + T + Q_t + Q_p$. Consider when $t \to \infty$, then $N_t \to \frac{\Lambda}{\mu}$, , implying that $0 \le N \le \frac{\Lambda}{\mu}$. Thus, the considered region for this model is $\Gamma = \left\{(P, A, T, Q_t, Q_p) \in \Re_+^5 : N \le \frac{\Lambda}{\mu}\right\}$. All solutions of this model are bounded and enter the region Γ. Hence, Γ is a positively invariant. That is every solution of this model remains there for all $t > 0$.

2.2 Equilibrium point

There are two main equilibrium points in this model. The first one is an addiction-free equilibrium point $E_0 = \left(\frac{\Lambda}{\mu}, 0, 0, 0, 0\right)$. The second one is an addiction-present equilibrium state $E_1 = (P^*, A^*, T^*, Q_t^*, Q_p^*)$ where $P^* = \frac{\Lambda}{\beta A^* + \mu}$,

$$A^* = \frac{1}{\beta}\left[\frac{\beta\Lambda(\mu+\gamma)(\mu+\alpha+\varepsilon)}{(\mu+\gamma)(\mu+\alpha+\varepsilon)(\mu+\phi) - \alpha\gamma(1-\sigma)\phi} - \mu\right], \quad T^* = \frac{\phi A^*}{\mu+\gamma},$$

$Q_t^* = \frac{\gamma(1-\sigma)\phi A^*}{(\mu+\gamma)(\mu+\alpha+\varepsilon)}$, and $Q_p^* = \frac{\gamma\sigma T^* + \varepsilon Q_t^*}{\mu}$.

2.3 Basic reproduction number (R_0)

Next, the basic reproduction number is determined by using next generation method (van den Driessche and Watmough, 2002). From our model, we have

$$R_0 = \frac{\beta\Lambda}{\mu(\mu+\phi)}.$$

2.4 Stability analysis

The local stability of this model is determined by constructing Jacobian matrix of the system of equations (1) - (5). We have

$$J(P,A,T,Q_t,Q_p) = \begin{bmatrix} -\beta A-\mu & -\beta P & 0 & 0 & 0 \\ \beta A & \beta P-(\mu+\phi) & 0 & \alpha & 0 \\ 0 & \phi & -(\mu+\gamma) & 0 & 0 \\ 0 & 0 & \gamma(1-\sigma) & -(\mu+\alpha+\varepsilon) & 0 \\ 0 & 0 & \gamma\sigma & \varepsilon & -\mu \end{bmatrix}.$$

Theorem 1. *(local stability at E_0) If $R_0 < 1$, the addiction-free equilibrium point (E_0) is locally asymptotically stable. If $R_0 > 1$, the addiction-free equilibrium point (E_0) is unstable.*

Proof. The Jacobian matrix of this addiction-free equilibrium point is

$$J(P,0,0,0,0) = \begin{bmatrix} -\mu & -\frac{\beta\Lambda}{\mu} & 0 & 0 & 0 \\ 0 & \frac{\beta\Lambda}{\mu}-(\mu+\phi) & 0 & \alpha & 0 \\ 0 & \phi & -(\mu+\gamma) & 0 & 0 \\ 0 & 0 & \gamma(1-\sigma) & -(\mu+\alpha+\varepsilon) & 0 \\ 0 & 0 & \gamma\sigma & \varepsilon & -\mu \end{bmatrix}.$$

From Jacobian matrix above, we set det $(J-\lambda I)=0$ to find eigenvalues. Hence, the first two eigenvalues are $\lambda_1 = \lambda_2 = -\mu < 0$. The rest of characteristic equation is considered in the form of $\lambda^3 + a_1\lambda^2 + a_2\lambda + a_3 = 0$,
where, $a_1 = 2\mu+\gamma+\alpha+\varepsilon-\frac{\beta\Lambda}{\mu}+\mu+\phi$, $a_2 = (\mu+\gamma)(\mu+\alpha+\varepsilon)$ $-\left(\frac{\beta\Lambda}{\mu}-(\mu+\phi)\right)(2\mu+\gamma+\alpha+\varepsilon)$ and
$a_3 = (\mu+\phi)(1-R_0)(\mu+\gamma)(\mu+\alpha+\varepsilon)-\phi\gamma(1-\sigma)$.

When $R_0 < 1$, we obtain that $a_1 > 0, a_3 > 0$ and $a_1a_2 - a_3 > 0$, satisfying with Routh-Hurwitz criteria for $n = 3$. Hence, the addiction-free equilibrium point is locally asymptotically stable when $R_0 < 1$. However, when $R_0 > 1$ it does not satisfy with Routh-Hurwitz criteria, therefore, unstable.

Theorem 2. *(local stability at E_1) When $R_0 > 1$, the addiction-present equilibrium point (E_1) is stable if it satisfies the Routh-Hurwitz criteria.*

Proof. The addiction-present equilibrium point (E_1) exists when $R_0 > 1$ and the Jacobian matrix of the system of equations (1) - (5) at (E_1) is

$$J(P^*,A^*,T^*,Q_t^*,Q_p^*) = \begin{bmatrix} -\beta A^*-\mu & -\beta P^* & 0 & 0 & 0 \\ \beta A^* & \beta P^*-(\mu+\phi) & 0 & \alpha & 0 \\ 0 & \phi & -(\mu+\gamma) & 0 & 0 \\ 0 & 0 & \gamma(1-\sigma) & -(\mu+\alpha+\varepsilon) & 0 \\ 0 & 0 & \gamma\sigma & \varepsilon & -\mu \end{bmatrix}.$$

We set det $(J-\lambda I)=0$ to find eigenvalues. The first eigenvalue is $\lambda = -\mu < 0$. The rest of characteristic equation is considered in the form of $\lambda^4 + a_1\lambda^3 + a_2\lambda^2 + a_3\lambda + a_4 = 0$. Where,

$$\begin{aligned} a_1 &= \beta A^* + \mu + (\mu+\gamma) + (\mu+\alpha+\varepsilon) + (\mu+\phi) - \beta P^*, \\ a_2 &= \beta A^*(\mu+\phi) + \beta A^*(\mu+\gamma) + \beta A^*(\mu+\alpha+\varepsilon) + \mu[(\mu+\phi)+(\mu+\gamma)+(\mu+\alpha+\varepsilon)] \\ &\quad +(\mu+\phi)(\mu+\gamma)+(\mu+\phi)(\mu+\alpha+\varepsilon)+(\mu+\gamma)(\mu+\alpha+\varepsilon)-\mu\beta P^* \\ &\quad -\beta P^*(\mu+\gamma)\beta P^*(\mu+\alpha+\varepsilon), \\ a_3 &= \beta A^*(\mu+\phi)(\mu+\gamma)+\beta A^*(\mu+\phi)(\mu+\alpha+\varepsilon)+\beta A^*(\mu+\gamma)(\mu+\alpha+\varepsilon) \\ &\quad +\mu[(\mu+\phi)(\mu+\gamma)+(\mu+\phi)(\mu+\alpha+\varepsilon)+(\mu+\gamma)(\mu+\alpha+\varepsilon)-\beta P^*(\mu+\gamma)] \\ &\quad -\beta A^*(\mu+\alpha+\varepsilon)\mu+(\mu+\phi)(\mu+\gamma)(\mu+\alpha+\varepsilon)+\phi\alpha\gamma(1-\sigma) \\ &\quad -\beta P^*(\mu+\phi)(\mu+\gamma)(\mu+\alpha+\varepsilon) \text{ and} \\ a_4 &= \beta A^*(\mu+\phi)(\mu+\gamma)(\mu+\alpha+\varepsilon)+\mu[(\mu+\phi)(\mu+\gamma)(\mu+\alpha+\varepsilon) \\ &\quad -\beta P^*(\mu+\phi)(\mu+\gamma)(\mu+\alpha+\varepsilon)-\phi\alpha\gamma(1-\sigma)]-\beta A^*\phi\alpha\gamma(1-\sigma). \end{aligned}$$

By using Routh-Hurwitz criteria for $n=4$, this equilibrium point is stable if $a_1 > 0, a_3 > 0, a_4 > 0$ and $a_1a_2a_3 > a_3^2 + a_1^2a_4$.

2.5 Sensitivity analysis

The sensitivity indices are calculated by using the technique of the normalized forward sensitivity index (Ngoteya and Gyekye, 2015; Samsuzzoha *et al.*, 2013). By using the parameters value from Table 2, results are therefore given in Table 1. We obtained that increasing the value of μ and ϕ and reducing the value of β and Λ should be encouraged to reduce the value of basic reproduction number R_0.

Table 1: Numerical values of sensitivity indices of R_0

Parameters	Index at Parameter Value	Sign
β	+1	Positive
Λ	+1	Positive
μ	-1.4914	Negative
ϕ	-0.5086	Negative

2.6 Numerical simulation

In this section, the system of equations (1) - (5) are solved numerically. The parameters within this model are chosen as appropriate where some of them are the data of Thai population and are shown in Table 2. The numerical results are shown in figures 2 and 3.

Table 2. Parameters values used in numerical study.

Parameter	Description	Value	Description Reference
Λ	The recruitment rate of human population in Thailand.	8.61 per week	National Statistical Office, Thailand (2013)
β	The contact rate between potential addicted gamers and addicted gamers.	0.1 per week	Variable
ϕ	The rate of addicted gamers who go for treatment with therapeutic camp.	0.5 per week	Variable
α	The rate of addicted gamers who temporarily quit playing games revert back to be addicted gamers.	0.15 per week	Pornnoppadol (2013)
γ	The rate of quitting playing games of addicted gamers who get treatment with therapeutic camp.	0.72 per week	Pornnoppadol (2013)
σ	The fraction of addicted gamers who get treatment with therapeutic camp and permanently quit playing games	0.2 per week	Estimate
ε	The rate at which temporarily quitters become permanently quitters.	0.3 per week	Estimate
μ	The natural death rate of human population in Thailand.	0.483 per week	National Statistical Office, Thailand (2013)

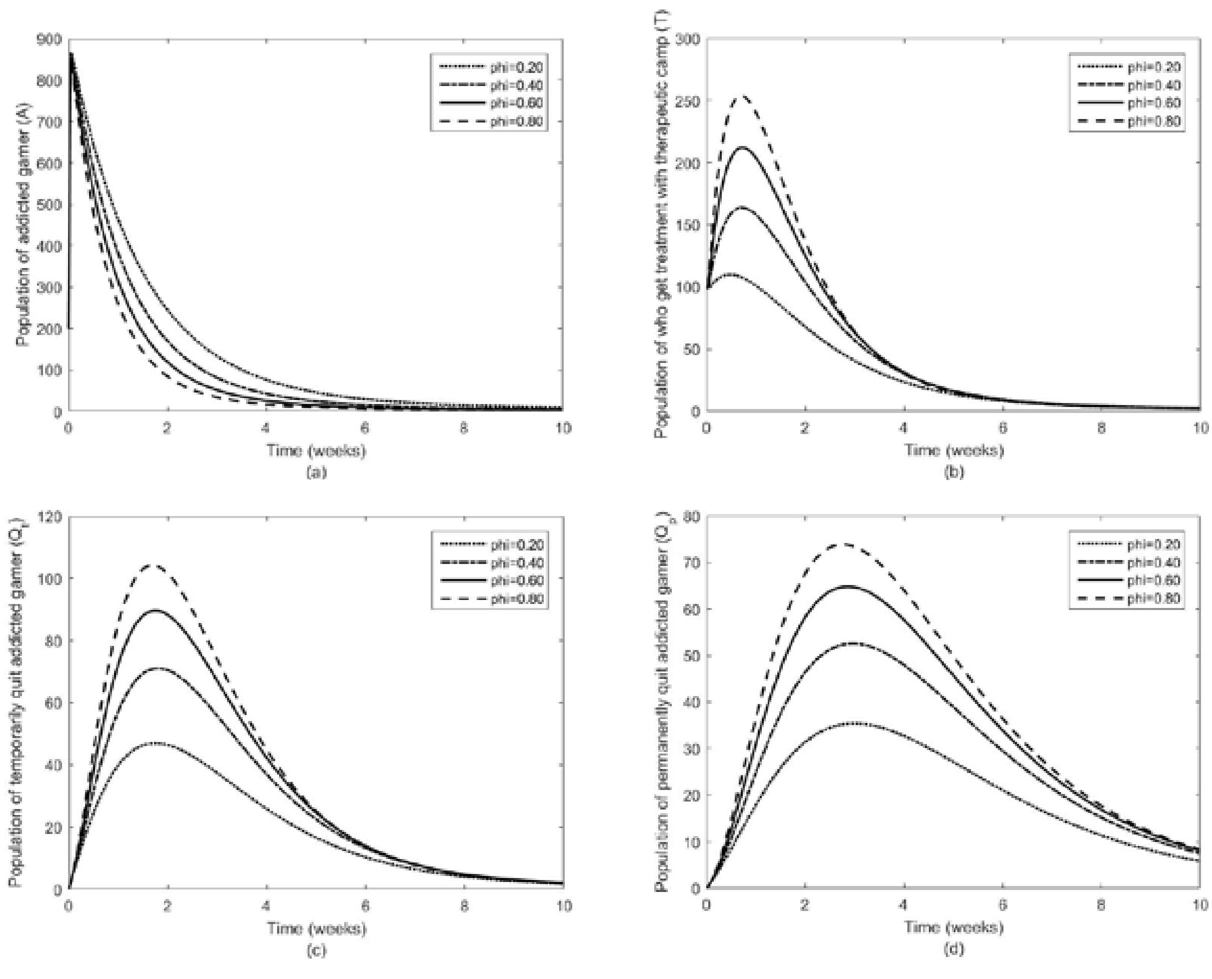

Figure 2. Numerical solution of system of equations (1) – (5) obtained using parameters: $\beta = 0.1, \Lambda = 8.61, \mu = 0.483, \alpha = 0.15, \sigma = 0.2, \varepsilon = 0.3, \gamma = 0.72$, when $\phi = 0.20, 0.40, 0.60, 0.80$ varies.

Figure 2(a) shows the dynamics of the model when the rate of addicted gamers who go for treatment with a therapeutic camp varies. When ϕ increases from $\phi = 0.20$ to 0.80, it demonstrates no changes in dynamics of the number of addicted gamers. Figure 2(b) shows a large increase in the number of addicted gamers who go for treatment with a therapeutic camp when ϕ increases although timing of the peak to occur at all values of ϕ are the same. Figure 2(c) and (d) gives similar results i.e. when ϕ increases, the peak of both Q_t and Q_p increases, this means that when there are more game addicted individuals who go for treatment, the number of both addicted gamers who decide to quit playing game either temporarily or permanently is increased, giving a better situation.

3. Optimal Control

In this section, we apply optimal control in our model developed in section 2. We consider the two control variables, which are u_1 representing the rate of therapeutic camp control for addicted gamers, and u_2 representing the rate of family understanding control for addicted gamers. A diagram of this control model is shown in Figure 3 below.

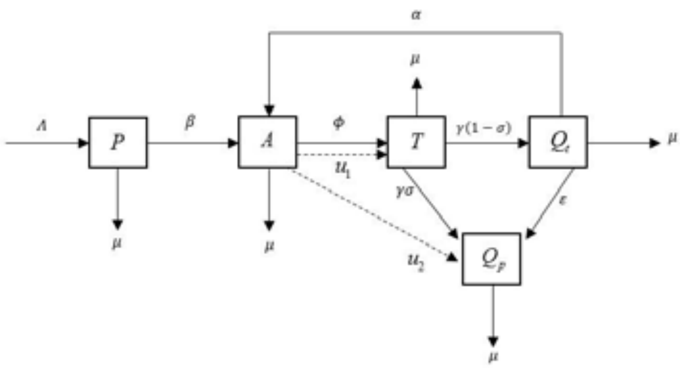

Figure 3. Diagram of the optimal control model of online game addiction in Thailand.

This model can be written as system of control equations as follows:

$$\frac{dP}{dt} = \Lambda - \beta PA - \mu P \tag{6}$$

$$\frac{dA}{dt} = \beta PA + \alpha Q_t - (\mu + \phi)A - (u_1 + u_2)A \tag{7}$$

$$\frac{dT}{dt} = \phi A + u_1 A - (\mu + \gamma)T \tag{8}$$

$$\frac{dQ_t}{dt} = \gamma(1-\sigma)T - (\mu + \alpha + \varepsilon)Q_t \tag{9}$$

$$\frac{dQ_p}{dt} = \gamma\sigma T + \varepsilon Q_t + u_2 A - \mu Q_p. \tag{10}$$

All parameters definitions are the same as in section 2. The model is analyzed basing on the theory of Pontryagin *et al.* (1986). For the optimal control model, we aim to minimize the concentration of the number of addicted gamers where the objective of the model is given by:

$$J(u_1, u_2) = \min \int_0^{t_f} \left[C_1 A(t) + \frac{1}{2} C_2 u_1^2 + C_3 u_2^2 \right] dt, \tag{11}$$

with initial conditions $P(0) \geq 0, A(0) \geq 0, T(0) \geq 0, Q_t(0) \geq 0, Q_p(0) \geq 0.$ The t_f is the period of treatment which is from 0 to 10 weeks in this model and the constants C_1, C_2 and C_3 are the benefit-cost of the treatment.

We can find an optimal solution of this optimal control problem by considering the Lagrangian and the Hamiltonian for the problem. The Lagrangian of the optimal control problem is given by

$$J(A, u_1, u_2) = C_1 A(t) + \frac{1}{2} C_2 u_1^2 + \frac{1}{2} C_3 u_2^2. \tag{12}$$

Applying Pontryagin's Maximum Principle (PMP), we form the Hamiltonian and derive the optimality system as follows:

$$\begin{aligned} H = {} & C_1 A(t) + \frac{1}{2} C_2 u_1^2 + \frac{1}{2} C_3 u_2^2 + \lambda_P \left[\Lambda - \beta PA - \mu P \right] \\ & + \lambda_A \left[\beta PA + \alpha Q_t - (\mu + \gamma)A - (u_1 + u_2)A \right] + \lambda_T \left[\phi A + u_1 A - (\mu + \gamma)T \right] \\ & + \lambda_{Q_t} \left[\gamma(1-\sigma)T - (\mu + \alpha + \varepsilon)Q_t \right] + \lambda_{Q_p} \left[\gamma\sigma T + \varepsilon Q_t + u_2 A - \mu Q_p \right], \end{aligned} \tag{13}$$

where $\lambda_P, \lambda_A, \lambda_T, \lambda_{Q_t}$ and λ_{Q_p} are the adjoint function associated with the state equations for P, A, T, Q_t and Q_p, respectively. The adjoint equations by setting

$P(t) = P^*, A(t) = A^*, T(t) = T^*, Q_t(t) = Q_t^*, Q_p(t) = Q_p^*$, are

$$\lambda_P' = -\frac{\partial H}{\partial P} = -\left[-\lambda_P(\beta A^* + \mu) + \lambda_A \beta A^* \right]$$

$$\lambda_A' = -\frac{\partial H}{\partial A} = -\left[C_1 - \lambda_P \beta P^* + \lambda_A(\beta P^* - (\phi + \mu) - (u_1 + u_2)) + \lambda_T(\phi + u_1) + \lambda_{Q_t} u_2 \right]$$

$$\lambda_T' = -\frac{\partial H}{\partial T} = -\left[-\lambda_T(\mu + \gamma) + \lambda_{Q_t}\gamma(1-\sigma) + \lambda_{Q_p}\gamma\sigma \right]$$

$$\lambda_{Q_t}' = -\frac{\partial H}{\partial Q_t} = -\left[\lambda_A \alpha - \lambda_{Q_t}(\mu + \alpha + \varepsilon) + \lambda_{Q_p}\varepsilon \right]$$

$$\lambda_{Q_p}' = -\frac{\partial H}{\partial Q_p} = -\left[\lambda_{Q_p}\mu \right].$$

The optimal control variables u_1^* and u_2^* are given by

$$u_1^* = \min\left\{\max\left\{\frac{(\lambda_A - \lambda_T)A^*}{C_2}, 0\right\}, u_{\max}\right\}, \text{ and}$$

$$u_2^* = \min\left\{\max\left\{\frac{(\lambda_A - \lambda_{Q_t})A^*}{C_3}, 0\right\}, u_{\max}\right\},$$

where it is subject to the constraint $0 \le u_1 \le u_{\max}$ and $0 \le u_2 \le u_{\max}$.

The numerical results of this optimal control model are shown in Figure 4 and 5. We use the forward-backward sweep method and solved the optimality system numerically. We consider the optimal control continuously for 10 weeks and use the parameter values represents in Table 2 where we set $N = 500$ the weight constants are $C_1 = 0.005$, $C_2 = 10$ and $C_3 = 10$.

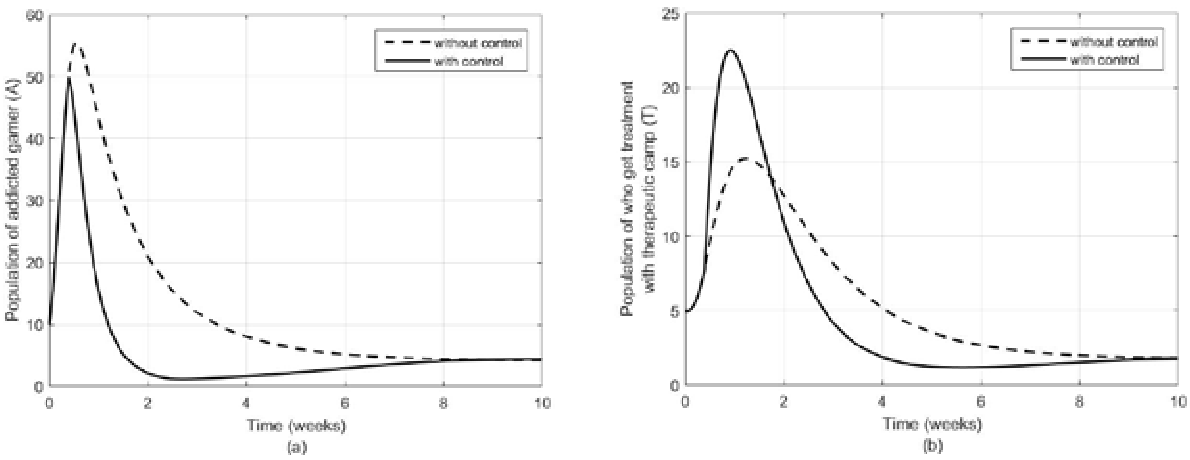

Figure 4. Numerical simulation of population of addicted gamers and addicted gamers who get treatment with therapeutic camp with and without control.

It is clearly seen from Figure 4(a) that although the number of addicted gamers population level has been reduced slightly with the control condition, once it reached the peak its dynamics dropped dramatically, giving a better situation than without control one. Figure 4(b) demonstrates that with control condition the number of addicted gamers who get treatment with therapeutic camp significantly increases.

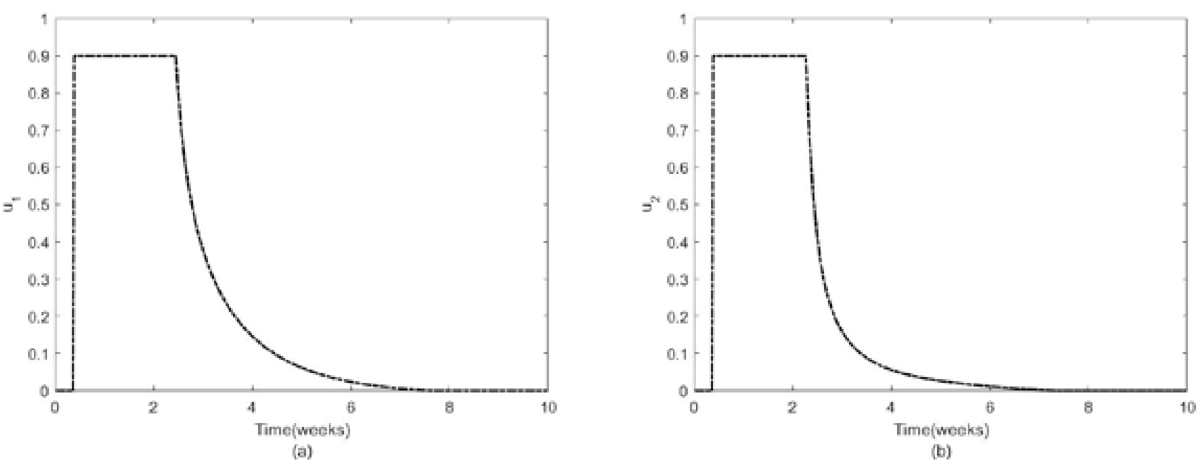

Figure 5. Dynamic of therapeutic camp control and family understanding control.

Figure 5(a) shows that the rate of therapeutic camp control remains at the rate of zero until the 0.4^{th} week and reaches the maximum rate of 0.9 until around the third week but then reduces to zero on the seventh week. Further, similar pattern of family understanding control is obtained in Figure 5(b).

4. Conclusions

In this paper, we study the dynamics of online game addiction of children and youth in Thailand by developing a $PATQ_tQ_p$ model involving the effects of a therapeutic camp for those who are addicted to online games and family understanding on stability of the model. Two main equilibrium points (addiction-free and addiction-present ones) are obtained and the basic reproduction number is

$R_0 = \frac{\beta\Lambda}{\mu(\mu+\phi)}$. The results show that the addiction-free equilibrium point is locally asymptotically stable if $R_0 < 1$ and unstable otherwise. As for the addiction-present equilibrium point, it is locally asymptotically stable when its coefficients of characteristic equation atisfy the Routh-Hurwitz criteria. Our sensitivity analysis and numerical simulations suggest that both the therapeutic camp for addicted gamers and family understanding are important factors that should be encouraged as a promising approach to reduce the level of online game addiction in Thailand.

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