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Role of technology in combating social crimes: A modeling study

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In this paper, a non-linear mathematical model is proposed and analysed to study the role of technology in combating social crimes in a dynamic population by considering immigration and emigration rates of susceptible population and criminals. The problem is modelled by considering five interacting variables, namely the density of susceptible population, the density of criminals, the density of removed (isolated) criminals, the density of crime burden and the level of technology used to control crime. The proposed model is analysed by using the stability theory of differential equation and simulation. The model analysis shows that the crime burden decreases considerably as the level of technology increases. It is noted that the crime in a society can be controlled almost completely if criminals from the general population are removed by intensive use of technology.

Key words: Crime; Crime Burden; Technology; Mathematical Modeling

1 Introduction

Crime is a major problem facing all societies in the world which needs to be controlled. It is a term associated with undesirable activities, such as burglary, theft, larceny, murder etc., in a society done by some individuals called criminals [25]. Crime depends upon many factors such as population density, age distribution of populations, transient or stable population, dense neighbourhoods, number of educational and commercial establishments, education level of people, economic conditions, poverty, social systems, unemployment etc. Crime is regarded as social when it represents a conscious challenge to a prevailing social order and its values. Social crime refers to all criminal and violent activities as mentioned above provoked by social factors that create an unsafe society, and prevent the restoration of social order (http://www.info.gov.za/view/DownloadFileAction?id=156928) [23].

The term ‘crime burden’ on the society may be defined as the impact (loss in the form of human lives, property etc.) caused by the aftermath of crime committed by criminals [2, 11]. Generally, it is directly related to the number of crimes, which is proportional to the number of criminals in a society. Thus, it can be measured by the *data* from the sources such as first information reports in police stations, communications from NGOs etc.

There seems to be a correlation between poverty and crime, as persons living in poverty are more inclined and tempted to commit social crimes [7,17,25]. Immigration of criminals also plays an important role in increasing crime burden on a society, and a major proportion of crime in the United States has been committed by illegal immigrants [18,22]. It has been noted that a sound methodology, knowledge of factual data and the ability to examine crime in the context of broader social, political, technological, historical and economic sense is necessary to control crime in a society [8,14,15].

As technology evolves, law enforcement, government and other agencies use strategies and practices to reduce the risk posed by criminals. The punishment to criminals and putting them into isolation is very helpful in controlling increasing rate of crime in a society [4, 13]. It has been suggested that technology can be used for detecting and preventing crimes and to provide security to people (http://www.mops.gov.il/BPEng/Crime+Prevention/Using+Technology+to+Prevent+Crime/) [5]. It has been found that a better watch and patrol helped in reducing the number of violent crimes in a society [6,14,16,22].

In recent decades, many researchers have studied the problem of crime in a society by using various methods [1,4,10,21,24,25]. In particular, Ahmed and Rahim [1] have proposed a dynamic model for crime control and policy evaluation. Becker [4] used the concept of economic theory by assuming that individuals are tempted to commit a crime if the risk is much lower than the benefits gained [7,17]. The approach similar to mathematical biology, as in the spread of epidemics, has been used to study the dynamics of crime [21,25]. In particular, Zhao *et al.* [25] have used a model consisting of ordinary differential equations to study the dynamics of poverty and crime by using the stability theory. They have divided the population into five sub-classes, namely the general people (not poor), the poor class, the class of criminals, the jailed class and the recovered class. In their study, they have assumed population to be constant. However, this is not the case in real world scenario, as in all cities of the world people immigrate for employment and other purposes. For example, about 3,100 legal immigrants and 2,000 illegal immigrants settle down in the United States everyday (http://www.fbi.gov/ucr/05cius/data/table 01.html; http://www.mops.gov.il/BPEng/Crime+Prevention/Using+Technology+to+Prevent+Crime/; http://www.uncjin.org/Statistics/WCTS/trc000927.pdf) [7,22]. Criminals also do immigrate to a community to become aware of the situation so that the crime can be committed easily. They also try to involve general people in the process of criminal activities by inducing them through monetary benefits (http://www.census.gov/compendia/statab/cats/law_enforcement_courts_prisons/crimes_and_crime_rates.html; http://www.nyc.gov/html/nypd/html/pct/cspdf.html) [8, 18–21]. In a recent work, Curtis and Smith [9] have also analysed the role of technology through a study representing the effect of enhancement of security on crime statistics.

In Third World countries, where a large number of general population is not very rich, the poor people as well as criminals are part of this general population. Since the rich people live in highly isolated and secured locations where they have their own security, and are unaffected by criminals, they may be ignored in the model study [19]. Therefore, to study the dynamics of crime, a more realistic model has to be proposed and analysed by keeping in mind the growth of general population by immigration where criminals may also immigrate. In most of the studies cited above, neither the level of crime burden has been taken into account nor the level and impact of technology available today in detecting and controlling crimes simultaneously is considered in the modelling process. Thus, in this paper we propose a non-linear model by considering the following five interacting variables: (i) the density of general population which is susceptible to criminal activities; (ii) the density of criminals; (iii) the density of removed (isolated) criminal class or jailed class which has been detected and isolated by security forces using modern technology; (iv) the density of crime burden which is proportional to density of criminals and (v) the level of technology which is assumed to be applied in proportion to crime burden which can be easily found out from the first information reports in police stations. The focus of this paper, therefore, is to study the role of technology in combating social crimes in a society [3, 12].

2 Mathematical model

Let N be the density of population consisting of general people, criminals as well as recovered individuals. Let S be the density of susceptible population which is affected by criminals with density C present in the general population. Let R be the density of removed (quarantined jailed class) criminal class which is detected by security forces from criminal class using modern technology. Let C_b be the density of crime burden on society and T be the level of technological efforts used to prevent crime. The first three equations of model (2.1) resemble the SIRS epidemic model under the light of the parameters explained further in this section [21]. Let A_s be the legal immigration to the susceptible population and A_c be the immigration (illegal) to the criminal class. The coefficient β is the rate of change of susceptible class into criminal class after motivated interaction. The coefficient v is the effectiveness of level of technology for bringing criminals into recovered class with the help of interventions by security forces, and α_1 is the rate at which criminals stop committing crime without any external efforts and move to the removed class. The removed individuals may also leave the criminal background and become susceptible again at a rate of v_0. The constant α is the rate at which criminals emigrate. A removed individual may also become criminal at a reduced rate $v_1 R$.

As pointed out in the Introduction, crime burden on a society is directly related to the number of crimes, which is proportional to the number of criminals; therefore, let ϕ be the coefficient representing the growth of crime burden on the society assumed to be proportional to C and ϕ_0 is its depletion rate.

Since the introduction of new technology helps to reduce crime burden, the rate of growth of technology must increase with the growth of crime burden. Therefore, let ψ be the rate at which new technology to control crime is applied, which is assumed to be proportional to crime burden, and ψ_0 is the rate at which the technology becomes less effective or outdated.

Keeping in view of above considerations, the following model is proposed in the form of non-linear differential equations:

$$\frac{dS}{dt} = A_s + b - \gamma N - \beta SC - dS + v_0 R,$$
$$\frac{dC}{dt} = A_c + \beta SC - dC - \alpha C - vCT - \alpha_1 C + v_1 R,$$

$$\frac{dR}{dt} = \nu CT - \nu_0 R - \nu_1 R - dR + \alpha_1 C,$$
$$\frac{dC_b}{dt} = \phi C - \phi_0 C_b,$$
$$\frac{dT}{dt} = \psi C_b - \psi_0 T, \tag{2.1}$$

where $S(0) > 0,\ C(0) > 0,\ R(0) > 0,\ C_b(0) > 0,\ T(0) > 0.$

In model (2.1), d is the natural death rate, and b represents the constant birth rate of the population with density N. Therefore, in model (2.1) there is a constant immigration rate of susceptible population, A_s, along with constant birth rate b, and a standard emigration rate γN, plus an extra criminal emigration rate αC. In the following analysis all parameters in the model are assumed to be positive and constant.

Since $N = S + C + R$, by adding the first three equations, we get

$$\frac{dN}{dt} = A_s + b + A_c - dN - \gamma N - \alpha C. \tag{2.2}$$

Equation (2.2) shows that the total population is not a constant but varies due to immigration, death rate etc.

Making use of (2.1) and (2.2), it would suffice to analyse the following model where the first equation of (2.1) is not considered and $S = N - C - R$ is used.

$$\begin{aligned}
\frac{dC}{dt} &= A_c + \beta(N - C - R)C - dC - \alpha C - \nu CT - \alpha_1 C + \nu_1 R,\\
\frac{dR}{dt} &= \nu CT - \nu_0 R - \nu_1 R - dR + \alpha_1 C,\\
\frac{dC_b}{dt} &= \phi C - \phi_0 C_b,\\
\frac{dT}{dt} &= \psi C_b - \psi_0 T,\\
\frac{dN}{dt} &= A_1 + A_c - d_1 N - \alpha C,
\end{aligned} \tag{2.3}$$

where

$$A_1 = A_s + b,$$
$$d_1 = d + \gamma.$$

The above model is analysed in the following two cases:

(i) $A_c \neq 0$: This case represents the scenario where there is illegal immigration.

(ii) $(A_c = 0)$: This case represents the scenario where there is no illegal immigration.

It can be noted here that the variables C, R, C_b, T and N positive in the invariant region Ω are found as follows:

$$\begin{aligned}
\Omega = \{(C, R, C_b, T, N)/0 < C < N_{\max}, 0 \leqslant R < N_{\max}, 0 < C_b \leqslant \frac{\phi N_{\max}}{\phi_0},\\
0 \leqslant T \leqslant \pi N_{\max}, N_{\min} \leqslant N < N_{\max}\},
\end{aligned} \tag{2.4}$$

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where

$$N_{\min} = \frac{(A_c + A_1)}{(d_1 + \alpha)}, \tag{2.5}$$

$$N_{\max} = \frac{(A_c + A_1)}{d_1}, \tag{2.6}$$

$$\pi = \frac{\phi\psi}{\phi_0\psi_0}.$$

3 Equilibrium analysis for case (i): $A_c \neq 0$

In this case, model (2.3) has only one non-negative equilibrium $E^*(C^*, R^*, {C_b}^*, T^*, N^*)$, where C^*, R^*, ${C_b}^*$, T^*, N^* are determined from the following algebraic equations obtained by putting the right-hand sides of the equations of model (2.3) to zero,

$$0 = A_c + \beta(N - C - R)C - dC - \alpha C - \nu CT - \alpha_1 C + \nu_1 R, \tag{3.1}$$

$$0 = \nu CT - \nu_0 R - \nu_1 R - dR + \alpha_1 C, \tag{3.2}$$

$$0 = \phi C - \phi_0 C_b, \tag{3.3}$$

$$0 = \psi C_b - \psi_0 T, \tag{3.4}$$

$$0 = A_1 + A_c - d_1 N - \alpha C. \tag{3.5}$$

Solving the above algebraic equations, we get the following two isoclines governing N^*, C^*. We get equation (3.6) after combining equations (3.1)–(3.4), and equation (3.7) after rewriting equation (3.5),

$$\beta N = -\frac{A_c}{C} + (d_1 + \alpha + \alpha_1) - \frac{\nu_1\alpha_1}{d_1 + \nu_0 + \nu_1} + \nu\pi C\left(1 - \frac{\nu_1}{d_1 + \nu_0 + \nu_1}\right) + \beta C\left(1 + \frac{\nu\pi C + \alpha_1}{d_1 + \nu_0 + \nu_1}\right), \tag{3.6}$$

$$N = \frac{1}{d_1}(A_1 + A_c - \alpha C). \tag{3.7}$$

From the isocline (3.6) we note the following points:

(i) When $C \longrightarrow \infty;\ N \longrightarrow \infty$,

(ii) When $C \longrightarrow 0;\ N \longrightarrow -\infty$,

(iii) $\dfrac{dN}{dC} > 0$.

From isocline (3.7) the following facts can be noted:

$$(i)\ \text{When } C = 0;\ N = \frac{A_1 + A_c}{d}, \tag{3.8}$$

$$(ii)\ \text{When } N = 0;\ C = \frac{A_1 + A_c}{\alpha}, \tag{3.9}$$

$$(iii)\ \frac{dN}{dC} < 0. \tag{3.10}$$

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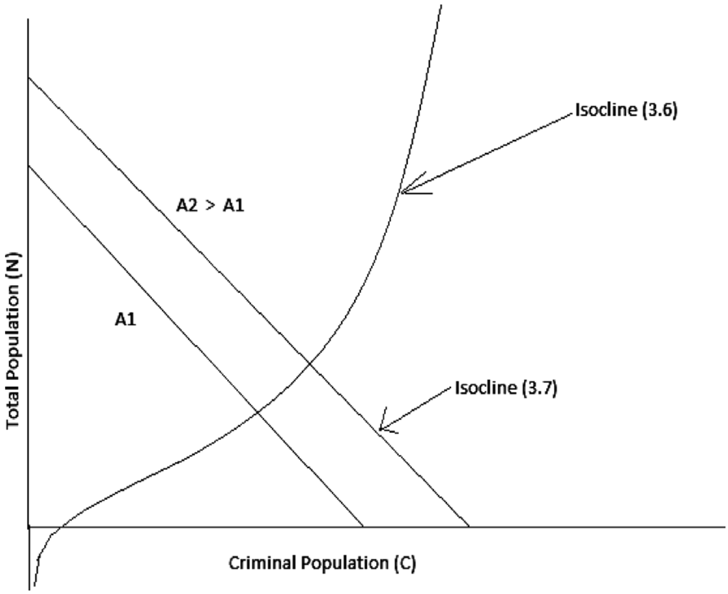

FIGURE 1. Qualitative plot of isoclines (3.6) and (3.7) and the existence of equilibrium $E^*(N^*, C^*)$ for various values of A_s.

Intersection of above two isoclines shows the existence of an equilibrium (N^*, C^*) (see Figure 1). It can also be noted from Figure 1 that as A_s increases, N^* increases. After finding the equilibrium (N^*, C^*) we can easily determine $R^*, {C_b}^*$ and T^* as follows:

$$ {C_b}^* = \frac{\phi C^*}{\phi_0}, \;\; T^* = \frac{\psi {C_b}^*}{\psi_0}, \;\; R^* = \frac{(v C^* T^* + \alpha_1 C^*)}{(v_0 + v_1 + d_1)}. $$

Remarks 1 From model (2.3), it can be noted that $\frac{dC_b}{d\psi} < 0$, $\frac{dC_b}{dv} < 0$ etc. The first condition implies that crime burden decreases as technology increases. The second condition implies that crime also decreases when criminals are removed from the criminal class and jailed/isolated.

4 Stability analysis

To analyse the stability of equilibrium E^*, we proceed as follows:

For local stability, we consider the following positive definite function:

$$ V = \tfrac{k_1}{2}(c)^2 + \tfrac{k_2}{2}(r)^2 + \tfrac{k_3}{2}(c_b)^2 + \tfrac{k_4}{2}(\tau)^2 + \tfrac{k_5}{2}(n)^2, $$

from which $\frac{dV}{dt}$ can be calculated by using the linearized version of (2.1) about equilibrium E^*. For local stability, $\frac{dV}{dt}$ needs to be negative in Ω, which is ensured under the following conditions:

$$ \max\left\{ \frac{3(vC^*)^2}{2\psi_0(d_1+v_0+v_1)}, \; \frac{9(\frac{vT^*+\alpha_1}{\beta})v^2}{4\psi_0(A_c+v_1R^*+\beta C^{*2})} \right\} < \frac{4k_3\phi_0\psi_0}{9\psi^2}, \tag{4.1} $$

$$ \left(\frac{vT^*+\alpha_1}{\beta C^*}\right)\left(\frac{v_1}{C^*}\right)^2 < \frac{2(d_1+v_0+v_1)(A_c+v_1R^*+\beta C^{*2})}{3C^*}, \tag{4.2} $$

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where

$$k_1 = \frac{(\nu T^* + \alpha_1)}{\beta C^*}, k_2 = 1, k_5 = \nu T^* + \alpha_1,$$
$$0 < k_3 < \frac{2k_1\phi_0(A_c + \nu_1 R^* + \beta C^{*2})}{3\phi^2 C^*},$$
$$\max\left\{\frac{3(\nu C^*)^2}{2\psi_0(d_1+\nu_0+\nu_1)}, \frac{9k_1\nu^2 C^*}{4\psi_0(A_c+\nu_1 R^* + \beta C^{*2})}\right\} < k_4 < \frac{4k_3\phi_0\psi_0}{9\psi^2}.$$

For non-linear stability, we consider the following positive definite function:

$$W = \frac{c_1}{2}\left(C - C^* - C^* ln\left(\frac{C}{C^*}\right)\right) + \frac{c_2}{2}(R - R^*)^2 + \frac{c_3}{2}(C_b - C_b{}^*)^2 + \frac{c_4}{2}(T - T^*)^2 + \frac{c_5}{2}(N - N^*)^2,$$

from which $\frac{dW}{dt}$ can be calculated by using (2.1). For E^* to be non-linearly stable, $\frac{dW}{dt}$ needs to be negative in Ω, which is ensured under the following conditions:

$$\max\left\{\frac{3(\nu N_{\max})^2}{2\psi_0(d_1+\nu_0+\nu_1)}, \frac{9(\frac{\nu T^*+\alpha_1}{\beta})\nu^2 C^* N_{\max}}{4\psi_0(A_c+\beta C^* N_{\max})}\right\} < \frac{4c_3\phi_0\psi_0}{9\psi^2}, \tag{4.3}$$
$$\left(\frac{\nu T^*+\alpha_1}{\beta}\right)\left(\frac{\nu_1}{C^*}\right)^2 < \frac{2(d_1+\nu_0+\nu_1)(A_c+\beta C^* N_{\max})}{3C^* N_{\max}}, \tag{4.4}$$

where

$$c_1 = \frac{(\nu T^*+\alpha_1)}{\beta}, c_2 = 1, c_5 = \nu T^* + \alpha_1,$$
$$0 < c_3 < \frac{2c_1\phi_0(A_c+\beta C^* N_{\max})}{3\phi^2 C^* N_{\max}},$$
$$\max\left\{\frac{3(\nu N_{\max})^2}{2\psi_0(d+\nu_0+\nu_1)}, \frac{9c_1\nu^2 C^* N_{\max}}{4\psi_0(A_c+\beta C^* N_{\max})}\right\} < c_4 < \frac{4c_3\phi_0\psi_0}{9\psi^2}.$$

Remarks 2 It is noted from (4.1)–(4.4) that parameters such as ν, ν_1, ϕ have destabilizing effects on the system.

The above discussions imply that under certain conditions the system variables would attain equilibrium values. It also implies that crime burden decreases as the level of technology applied to combat crime increases, but it decreases further if criminals are separated from the society in the form of recovered/jailed criminals.

5 Analysis for case (ii): $A_c = 0$

Model (2.3) has two non-negative equilibria for $A_c = 0$, namely:

(i) Crime free equilibrium, $E_1(\frac{A_1}{d_1}, 0, 0, 0, \frac{A_1}{d_1})$.

This equilibrium is locally stable.

(ii) Equilibrium in the presence of crime, $E_2(\hat{S}, \hat{C}, \hat{C}_b, \hat{T}, \hat{N})$.

All the results for E_2 can be obtained by putting $A_c = 0$ in respective equations of the previous case. In particular, the following may be noted:

(i) The stability conditions for case (ii) are similar to that for case (i). These can be derived by putting $A_c = 0$ in (4.1)–(4.4).

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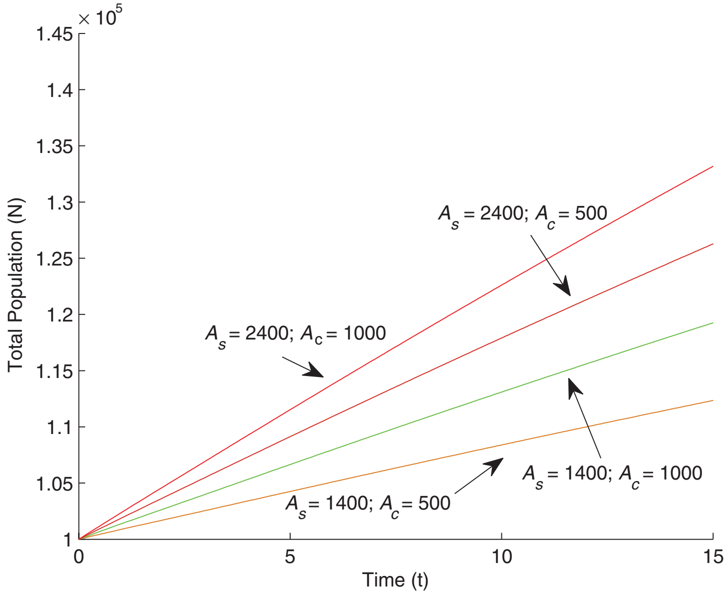

FIGURE 2. (Colour online) Total population variation in years (0–15).

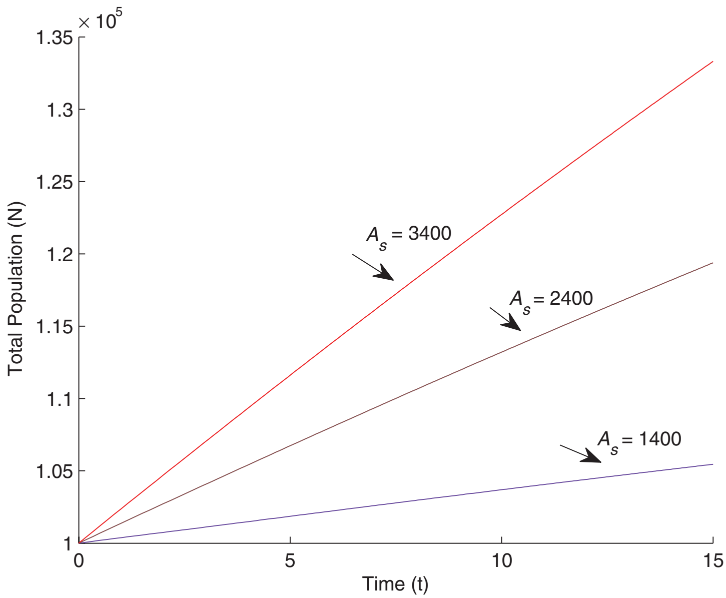

FIGURE 3. (Colour online) Total population w.r.t. time (yrs.) for various values of A_s when $A_c = 0$.

(ii) The equilibrium level of the density of criminals when $A_c \neq 0$ is greater than the equilibrium level of the density when $A_c = 0$.

In the following, we conduct simulation analysis to compare the two cases by solving model (2.3) using Matlab 7.0.

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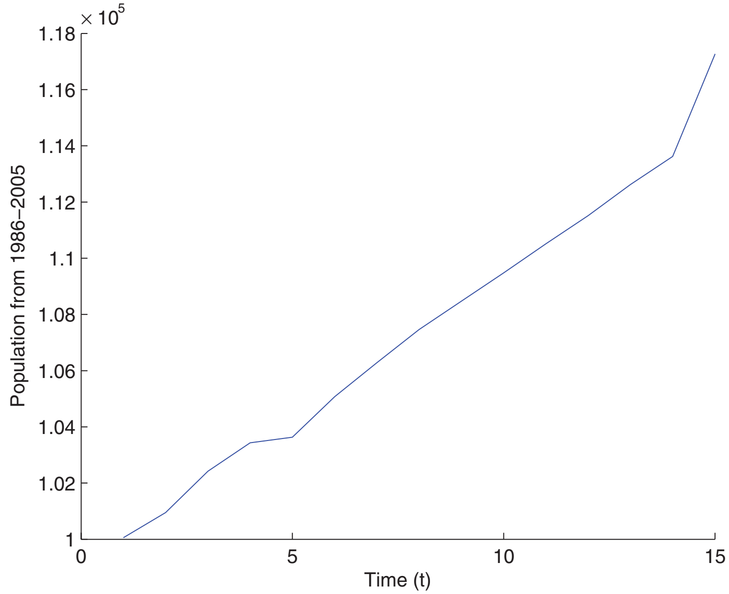

FIGURE 4. (Colour online) The US statistics of population growth (http://www.fbi.gov/ucr/05cius/data/table 01.html).

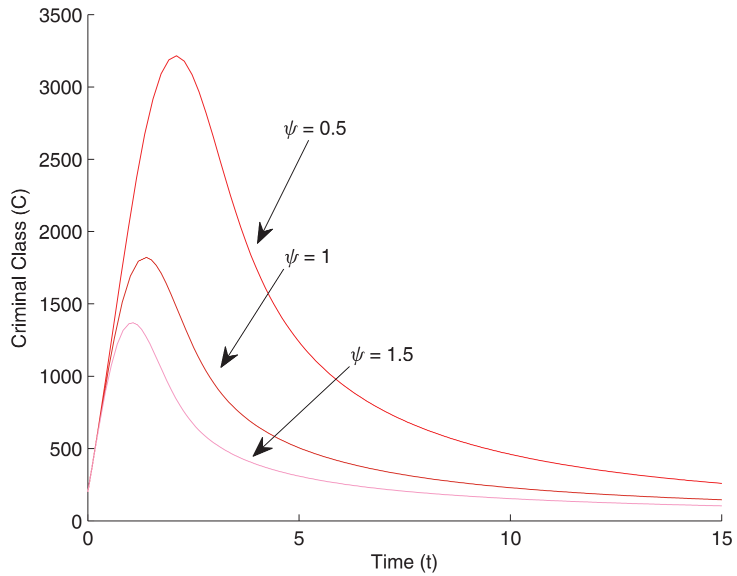

FIGURE 5. (Colour online) Variation in criminal class for different values of ψ.

6 Simulation and discussion

To check the feasibility of our analysis regarding the existence of E^* and the corresponding stability conditions, we conduct some numerical computation of model (2.3) by choosing the following values of parameters. The parameters are chosen such that

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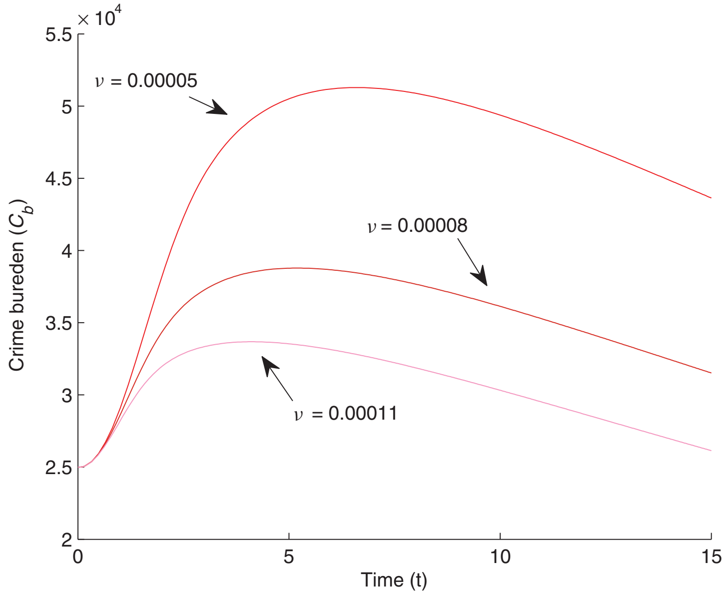

FIGURE 6. (Colour online) Variation in crime burden on society for different values of ν.

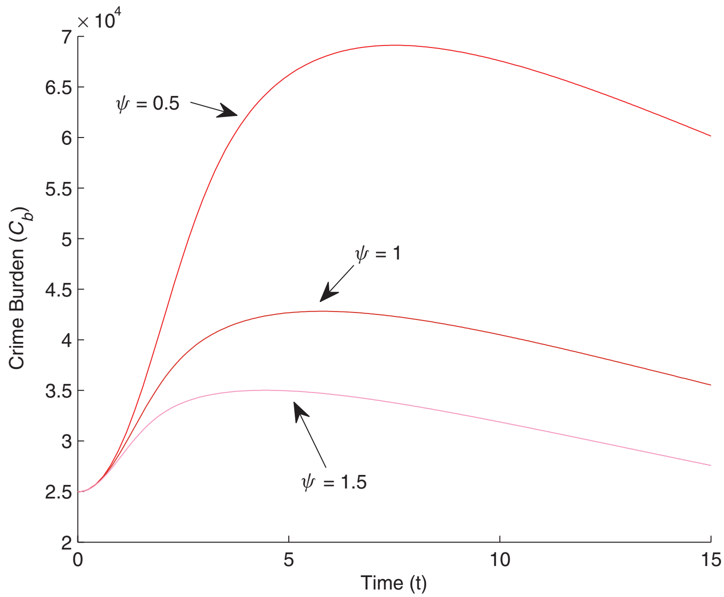

FIGURE 7. (Colour online) Variation in crime burden on society for different values of ψ.

the plots will show same trends as in the real world (Figures 4, 9 and 10) for data (http://www.fbi.gov/ucr/05cius/data/table 01.html). Initial total population is considered to be 0.1 million.

$A_1 = 1{,}600, A_s = 1{,}400, d_1 = 0.01, d = 0.005, \beta = 0.00001, \alpha = 0.02, A_c = 500, \alpha_1 = 0.005,$
$\nu_1 = 0.5, \nu_0 = 0.1, \nu = 0.00005, \phi = 5, \phi_0 = 0.05, \psi = 0.75, \psi_0 = 0.005, b = 200.$

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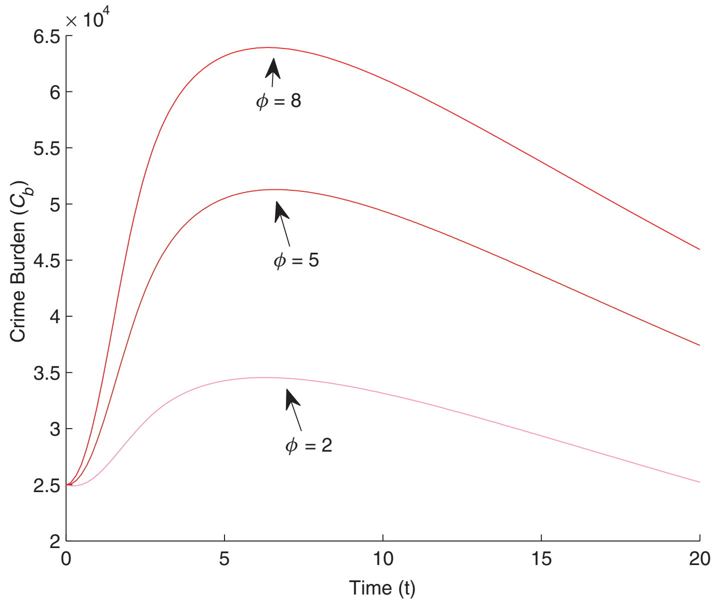

FIGURE 8. (Colour online) Variation in crime burden on society for different values of ϕ.

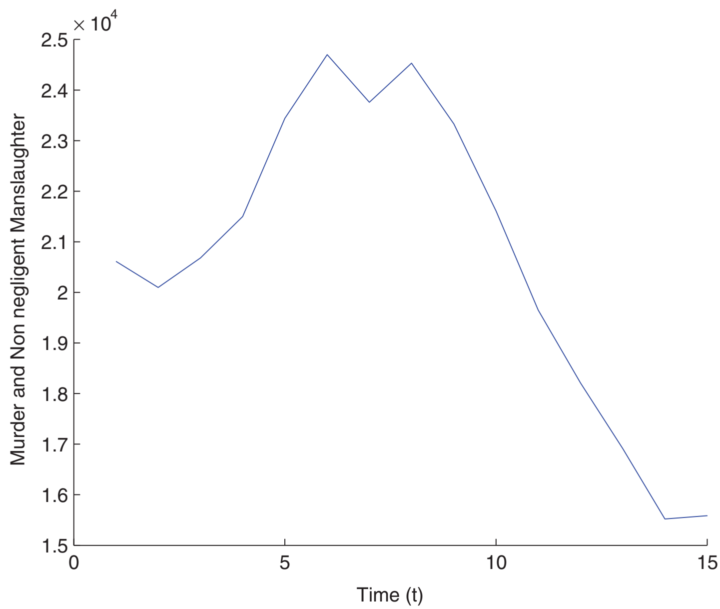

FIGURE 9. (Colour online) The US statistics for murder and non-negligent manslaughter (http://www.fbi.gov/ucr/05cius/data/table 01.html).

The equilibrium values of the coordinates of E^* are found as follows:

$$N^* = 2.1E5, C^* = 263, R^* = 8.4E4, C_b^* = 26300, T^* = 3.9E6.$$

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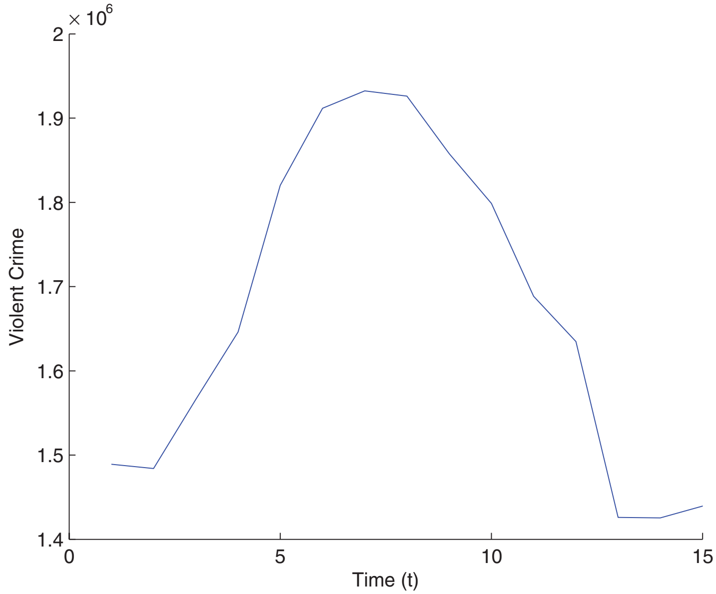

FIGURE 10. (Colour online) The US statistics for violent crime (http://www.fbi.gov/ucr/05cius/data/table 01.html).

Model (2.3) is solved for various variables for the above-mentioned parameters, and plotted in Figures 2–10.

From Figure 2, we can observe that as the legal and illegal immigrations increase, the total population increases.

From Figures 3 and 4, it is noted that the growth of total population in the model analysis and real world data are qualitatively similar.

It can be seen in Figure 5 that as technology increases, the density of criminals decreases and it takes much less time to reach its equilibrium.

It can be observed in Figure 6 that as the interaction coefficient between the level of technology and criminal activities increases, the density of crime burden on society decreases.

In Figure 7, the change in density of crime burden with time for different values of ψ is shown. We observe that when ψ increases, crime burden decreases.

By comparing Figure 6 and 7, it can be noted that v has a much greater effect on C_b in comparison to ψ, suggesting that isolation of criminals is very important in controlling social crimes.

It can be observed in Figure 8 that as ϕ increases, the crime burden on society decreases.

Figures 9 and 10 show plots for crime statistics for various types of social crime obtained for the United States (http://www.fbi.gov/ucr/05cius/data/table 01.html). It can be noted that the results obtained in the numerical simulation (Figures 6–8) are qualitatively similar to the real world data.

7 Conclusions

In this paper we proposed and analysed a non-linear model to study the role of technology on the control of crime in a society affected by criminals. In the modelling process, we have considered five interacting variables, namely (*i*) the density of general population, (*ii*) the density of criminal class, (*iii*) the density of removed criminal class, (*iv*) the level of crime burden on society and (*v*) the level of technology to prevent crime. The model described here is a very simple description of dynamics of crime and crime burden in a society and helps to understand the effect of increasing level of technology on control of crime. We have considered immigration both in general population and criminal class. It has been shown that if the level of technology increases, the equilibrium density of crime burden decreases. Further, it has been shown that due to illegal immigration, the society always has some latent crime in the population. It has also been noted that if illegal immigration is prevented completely, the crime burden may eventually be reduced. The simulations of the model have been conducted in both the cases of immigration and without immigration to confirm analytical results. It has been noted further that the results from the model are qualitatively similar to the real world data available in literature.

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