



Application of Modeling to Manage Examination Misconducts

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ABSTRACT

Examination misconduct is as old as education in Nigeria itself and its effect on the sector and the nation as a whole is crippling and retrogressive. This paper developed deterministic model for reducing examination misconducts. The model, which consists of four ordinary differential equations, was analyzed strictly. The model was extended and optimal control theory was applied to explore optimal strategies for scheming the spread of examination misconducts using rewards (including orientation) for the susceptible (honest) and the removed (quitters) students, appropriate supervision for those exposed (lightly involved) and imprisonment and expulsion for those infected (highly involved) students as the system control variables. The impact of using possible combinations of these three control strategies was investigated. Numerical simulations indicate success with the application of the control strategies reduction of the examination misconduct.

Keywords: Examination, misconducts, deterministic model and control

INTRODUCTION

Examination misconduct can be seen as an unpleasant practice encapsulating diverse types of cruel means adopted by unserious students to cheat during examinations sequentially to score high marks and pass in the examinations. Oko, Cfia, & Adie (2016) defined examination misconducts as any deliberate act of wrong doing, contrary to the rules of examinations designed to give a candidate an undue advantage. It is one of the numerous challenges facing Nigeria educational system, which was acknowledged by scholars to have existed for some time especially when our moral values began to fade in the 70s and 80s in this country. Since then, it has affected the educational integrity at all levels and in different types of examinations, both internal and external examinations. In the recent times, the unchecked incidence of examination misconduct has turned out to be an issue of growing significance and apprehension in the global education system. Virtually everyone's examinations are discernible by means of diverse forms of misconduct, and in the majority of these examinations, misconduct is a recurring incident (Petters & Okon, 2014).

However, all punishments introduced to bring to a halt remain almost ineffective if not absolutely fruitless. The reasons could be credited to societal value system, the behaviour

of candidates, parents and the education system. The consequences could be tragic to both education system and the society as it would turn out the society-certificated illiterates Oko, Cfia, & Adie (2016). According to Makaula (2018), students' performance in examinations forms the basis of important decisions about their educational and vocational futures. However, because of the importance attached to examination, its outcomes should be more credible and acceptable within the wider society. Adeniran, Bakare, & Akinpade, (2020) in their study indicated that examination misconduct sows seeds of deception and illicit values in our society, this vice cannot allow us to realize our prospect greatness because it renders our certificates useless and debases the foundation for assessing our skills and capacity. Consequently, they concluded that indiscipline among the students is a critical variable in students' involvement in examination malpractices in schools.

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Many literatures (Oko, Cfia, & Adie (2016), Petters & Okon, (2014), Makaula (2018), Adeniran, Bakare, & Akinpade, (2020)) investigated the causes, problems and other factors associated with examination misconducts. However, to the best of our knowledge none has developed mathematical model for the control of examination misconducts.

The paper is organized as follows: we started by presenting the deterministic mathematical model describing examination misconducts using the *SEIR* Model approach. The analysis of the equilibrium point were discussed next and then we extended the model to formulate an optimal control; to investigate the existence and characterization of the optimal control using the Pontryagin's Maximum principle. Thereafter, numerical results were used to illustrate our analytical findings and lastly, the conclusion.

METHODOLOGY

Model Formulation

A deterministic compartmental modeling approach was used to design a model of examination misconduct. The total student population at a time t , denoted by $a < 0$ and $b > 0$ was split into four sub groups consisting of the following classes: susceptible students (honest) S_e , exposed (lightly involved in examination misconducts) students E_e , infected (highly involved in examination misconducts) students I_e and the removed (quitters) students R_e . Hence,

$$N_h = S_e + E_e + I_e + R_e \quad (1)$$

Susceptible students: The susceptible students are generated via recruitment (admission), into the population at a constant rate $w_i > 0$ for $i = 1, 2, \dots, 10$. $V(> 0 \text{ in } \Omega)$. They diminished once the susceptible (honest) students interacts with either exposed or infected (involved in examination misconducts) students at a rate $\beta(E_e + I_e)$, where β is the force of infection between $(E_e + I_e)$. The students would experiences natural death at a rate μ , which gives

$$\frac{dS_e}{dt} = \Lambda_h - (\beta(E_e + I_e) + \mu)S_e$$

Exposed (lightly involved in examination misconducts) students: The population of the

exposed increases when susceptible began involvement in examination misconducts slightly (like copying from other students, telling each other answers). Since the process of quitting for those involved in examination misconducts was slow, some highly involved in examination misconducts who might have changed, would return to exposed class (at a rate γ). The population of exposed would decrease; when exposed students progressed to highly involved in examination misconducts class (at a rate δ), through natural death (at a rate μ). And they also decrease when they completely quit involvement in examination misconduct (at a rate k). The rate of change of the population of exposed (lightly involved in examination misconducts) was given by

$$\frac{dE_e}{dt} = \beta(E_e + I_e)S_e + \gamma I_e - (\mu + \delta + k)E_e$$

Infected (highly involved in examination misconducts) students: The highly involved in examination misconducts students were generated from the lightly involved in examination misconducts students who became highly involved in examination misconducts. This occurs at a rate δ . They decrease due to natural death (at a rate μ) and decline of students that were lightly involved in examination misconducts at a rate γ . The population would also reduce due to deaths inform of imprisonment and expulsion (at a rate μ_0). The rate of change of the population of infected (highly involved in examination misconducts) students was given by

$$\frac{dI_e}{dt} = \delta E_e - (\mu + \mu_0 + \gamma)I_e$$

Removed (quitters) students: The population of Removed (quitters) was generated from lightly involved in examination misconducts students who quit involvement in examination misconducts (at a rate k), and decreased due to natural death at rate μ . Thus, the rate of change of the population of quitters was given by

$$\frac{dR_e}{dt} = kE_e - \mu R_e$$

The description above culminates into the following system of differential equations:

$$\begin{aligned} \frac{dS_e}{dt} &= \Lambda_h - (\beta(E_e + I_e) + \mu)S_e \\ \frac{dE_e}{dt} &= \beta(E_e + I_e)S_e + \gamma I_e - (\mu + \delta + k)E_e \end{aligned}$$

$$\begin{aligned} \frac{dI_e}{dt} &= \delta E_e - (\mu + \mu_0 + \gamma)I_e \\ \frac{dR_e}{dt} &= kE_e - \mu R_e \end{aligned} \tag{2}$$

The associated model variables and parameters were described in Table 1 and 2.

Basic properties of the involvement in examination misconducts model

Positivity of Solutions

We assumed that all the parameters of the model (2) are positive and the initial conditions for (2) are

$$S_{e0}(0) > 0, E_{e0}(0) > 0, I_{e0}(0) > 0, R_{e0}(0) > 0 \tag{3}$$

Lemma 2.1 solutions of (2) and (3) satisfy

$$S_{e0}(0) > 0, E_{e0}(0) > 0, I_{e0}(0) > 0, R_{e0}(0) > 0 \text{ for all } t > 0.$$

Proof

From the first equation of the model (2) we have

$$\frac{dS_e}{dt} = \Lambda_h - (\beta(E_e + I_e) + \mu_h)S_e$$

Note that on $t \in [0, \infty)$ we have

$$S'_e \geq -(\beta(E_e + I_e) + \mu_h)S_e$$

So that $S_e(t) \geq \tilde{S}_e(t)$ where \tilde{S}_e is the solution of $S'_e \geq -(\beta(E_e + I_e) + \mu)S_e$

Satisfying $\tilde{S}_e(0) = S_e(0) > 0$. Clearly $\tilde{S}_e(t) > 0$ for all $t > 0$.

Following the same argument it can be shown that $E_e(t) > 0, I_e(t) > 0, R_e(t) > 0$ for all $t > 0$. The proof complete

Invariant regions

The examination misconducts model (2) would be analyzed in a biologically feasible region as follows. $(N_h; \text{With } S_e + E_e + I_e + R_e)$, consider the feasible region

$$D = D_h \subset \mathbb{R}_+^4$$

With

$$D_h = \left\{ (S_e, E_e, I_e, R_e) \in \mathbb{R}_+^4 : S_e + E_e + I_e + R_e \leq \frac{\Lambda_h}{\mu} \right\}$$

To established the positive invariance of \mathcal{D} , the solutions of \mathcal{D} remains in \mathcal{D} for all $t > 0$. The rate of change of student population is given by

$$N'_h(t) = \Lambda_h - \mu N_h(t) - \mu_0 I_c(t) \tag{4}$$

Assuming that death due to imprisonment and expulsion in highly involved in examination misconducts students is equal to zero (i.e. $\mu_0 = 0$), it then follows that

$$N'_h(t) \leq \Lambda_h - \mu N_h(t) \tag{5}$$

A standard comparison theorem (Lakshmikanthan *et al.*, 1998) can be used to show that

$$N_h(t) \leq N_h(0)e^{-\mu t} + \frac{\Lambda_h}{\mu}(1 - e^{-\mu t})$$

Specifically,

$$N_h(t) \leq \frac{\Lambda_h}{\mu}, \text{ if } N_h(0) \leq \frac{\Lambda_h}{\mu}.$$

Thus, the region \mathcal{D} is positively – invariant. Hence, it is sufficient to consider the dynamic flows generated in \mathcal{D} . The model can be considered as being epidemiological and mathematical well – posed in the region \mathcal{D} (Hethcote, 2000). It is therefore sufficient to consider the dynamics of the flow generated by model system in \mathcal{D} . This result is summarized below.

Lemma The region $D = D_h \subset \mathbb{R}_+^4$ is positively – invariant for the basic model (2.1) with non-negative initial conditions in \mathbb{R}_+^4

Disease – free equilibrium (DFE) and stability analysis

The model (2) has a DFE, obtained by setting the right-hand sides of the equations in (2) to zero, given by

$$E_0 = (S_e^*, E_e^*, I_e^*, R_e^*) = \left(\frac{\Lambda_h}{\mu}, 0, 0, 0 \right) \tag{6}$$

The linear stability of those involved in examination misconducts can be established using the next generation operator method (Mohammed, Yahya & Farah (2015) and Van den Driessche & Watmough, 2002) on the model equation (2.1), the matrix F and V , for the new infection terms and the remaining transfer terms, are respectively, given by:

$$F = \begin{vmatrix} \beta \frac{\Lambda_h}{\mu} & \beta \frac{\Lambda_h}{\mu} \\ 0 & 0 \end{vmatrix}$$

$$V := \begin{vmatrix} (\mu + \delta + k) & -\gamma \\ -\delta & (\mu + \mu_0 + \gamma) \end{vmatrix}$$

The threshold epidemiological of those involved in examination misconduct, denoted by $\mathcal{R}_0 = \rho(FV^{-1})$, where ρ denotes the spectral radius, is given by

$$\mathcal{R}_0 = \frac{\beta\Lambda_h(\mu + \mu_0 + \gamma + \delta)}{\mu(\mu^2 + (\mu_0 + k + \gamma + \delta)\mu + (\delta + k)\mu_0 + k\gamma)} \tag{7}$$

The threshold quantity \mathcal{R}_0 is the threshold epidemiological of examination misconducts model. It is the expected average number of new infections produced by interaction with exposed and infected students involved in examination misconducts when introduced into a completely susceptible (honest) student population.

Existence of endemic equilibrium point (EEP)

Next, conditions for the existence of endemic equilibria for the model (2) are explored. Let

$$E_1 = (S_e^{**}, E_e^{**}, I_e^{**}, R_e^{**})$$

be the arbitrary endemic equilibrium of model, in which at least one of the infected components of the model is non-zero. Setting the right-hand sides of the equations in model formulation to zero gives the following expressions.

$$\begin{aligned} S_e^{**} &= -\frac{\gamma\delta - kk_1}{\beta(k_1 + \delta)}, \\ E_e^{**} &= -\frac{k_1(\delta\mu\gamma - \mu kk_1 + \Lambda\beta k_1 + \Lambda\delta\beta)}{\beta(k_1\gamma\delta - k_1^2k + \delta^2\gamma - \delta kk_1)}, \\ I_e^{**} &= -\frac{\delta(\delta\mu\gamma - \mu kk_1 + \Lambda\beta k_1 + \Lambda\delta\beta)}{\beta(k_1\gamma\delta - k_1^2k + \delta^2\gamma - \delta kk_1)}, \\ R_e^{**} &= -\frac{k_1l(\delta\mu\gamma - \mu kk_1 + \Lambda\beta k_1 + \Lambda\delta\beta)}{\beta(k_1\gamma\delta - k_1^2k + \delta^2\gamma - \delta kk_1)\mu} \end{aligned}$$

where $k = \mu + \delta + k$

$$k_1 = \mu + \mu_0 + \gamma \tag{8}$$

Furthermore, using Theorem 2 of (Van den Driessche & Watmough 2002) the following result is established.

Theorem 1 (Van den Driessche & Watmough (2002)) the *DFE* of the model (1), given by

\mathcal{R}_0 is locally asymptotically stable (LAS) if $\mathcal{R}_0 < 1$ and unstable if $\mathcal{R}_0 > 1$

Model for Optimal Control Examination Misconduct

In this section, the basic model was extended to include the possible interventions in order to reduce or limit the proliferation of exposed (lightly involved in examination misconducts students) and the sudden increase of the infected (highly involved in examination misconducts) students in a population. The associated control model to derive optimal control with minimal cost was formulated. The control efforts u_1, u_2 and u_3 represent rewards for the susceptible and removed (quitters) students, appropriate supervision for exposed (lightly involved in examination misconducts) and imprisonment and expulsions for infected (highly involved in examination misconducts) students respectively. The model equation (2) becomes

$$\begin{aligned} \frac{dS_e}{dt} &= (1 - u_1)\Lambda_h - (1 - u_2)\beta(E_e + I_e)S_e - \mu S_e \\ \frac{dE_e}{dt} &= (1 - u_2)\beta(E_e + I_e)S_e + \gamma I_e - (\mu + \delta + k)E_e \\ \frac{dI_e}{dt} &= (1 - u_3)\delta E_e - (\mu + \mu_0 + \gamma)I_e \\ \frac{dR_e}{dt} &= (1 - u_1)kE_e - \mu R_e \end{aligned} \tag{9}$$

The factor of $1 - u_1(t)$ is a control function representing rewards (including orientation) aimed at reducing students involvement in examination misconducts. The factor of $1 - u_2(t)$ is a control function representing appropriate supervisions aimed at reducing exposed students (lightly involved in examination misconducts). The factor of $1 - u_3(t)$ is a control function which represented imprisonment and expulsions aimed at reducing highly involved in examination misconducts students. This could reduce the contact between the exposed (lightly involved in examination misconducts) and infected (highly involved in examination misconducts) students, which intern will reduce students involvement in examination misconducts. Investigating the optimal control efforts that would be needed to control involved in examination misconducts in

the society, an optimal control problem with the objective (cost) functional is given by

$$J(u) = \int_0^T [A_1 E_e + A_2 I_e + B_1 u_1^2 + B_2 u_2^2 + B_3 u_3^2] dt. \tag{10}$$

Where T the final time and the coefficients are A_1, A_2, B_1, B_2, B_3 are positive weights to balance the factors. The aim is to minimize the number of exposed (lightly involved in examination misconducts) and infected (highly involved in examination misconducts) students E_e, I_e while minimizing the cost of controls $u_1(t), u_2(t), u_3(t)$. Thus, we seek an optimal controls u_1^*, u_2^*, u_3^* such that

$$J(u_1^*, u_2^*, u_3^*) = \min_{u_1, u_2, u_3} \{J(u_1, u_2, u_3) | u_1, u_2, u_3 \in U\}$$

Where the control set is defined as

$$U = \{(u_1^*, u_2^*, u_3^*) | u_i(t) \text{ is Lebesgues measurable, } i = 1, 2, 3, 0 \leq u_i(t) \leq 1, t \in [0, T]\}. \tag{11}$$

Subject to the system (9) and appropriate initial conditions. The basic framework of this problem is to characterize the optimal control.

Existence of Control Problem

The term $A_1 E_e, A_2 I_e$ is the cost of infection (involved in examination misconducts) while $B_1 u_1^2, B_2 u_2^2$ and $B_3 u_3^2$ are the costs of reward, appropriate supervision and imprisonment and expulsions respectively. The necessary conditions that an optimal control must satisfy come from the Pontryagin’s Maximum Principle (Mohammed, Yahya and Farah 2014). The principle converts (9) – (10) into a problem of minimizing point wise a Hamiltonian H , with respect to u .

$$H = A_1 E_e + A_2 I_e + B_1 u_1^2 + B_2 u_2^2 + B_3 u_3^2 + \lambda_1 \{(1 - u_1) \Lambda_h - (1 - u_2) \beta (E_e + I_e) S_e - \mu S_e\} + \lambda_2 \{(1 - u_2) \beta (E_e + I_e) S_e + \gamma I_e - (\mu + \delta + k) E_e\} + \lambda_3 \{(1 - u_3) \delta E_e - (\mu + \mu_0 + \gamma) I_e\} + \lambda_4 \{(1 - u_1) k E_e - \mu R_e\} \tag{12}$$

Where $\lambda_i = 0, \text{ for } i = 1, 2, 3, 4$ are adjoint variables

Theorem 2: Given an optimal control u^* and solutions $(S_e^*, E_e^*, I_e^*, R_e^*)$ of the corresponding

state system (9) that minimizes $J(u_1, u_2, u_3)$ over U . Then there exists adjoint variables $\lambda_i = 0, \text{ for } i = 1, 2, 3, 4$, satisfying

$$\begin{aligned} -\lambda_1' &= -(\lambda_1 - \lambda_2)(-1 + u_2)(E_e + I_e)\beta + \lambda_1 \mu \\ -\lambda_2' &= -A_1 + \lambda_1(1 - u_2)\beta S_e - \lambda_2((1 - u_2)\beta S_e - \mu - \delta - k) - \lambda_3(1 - u_3)\delta - \lambda_4(1 - u_1)k \\ -\lambda_3' &= -A_2 + \lambda_1(1 - u_2)\beta S_e - \lambda_2((1 - u_2)\beta S_e + \gamma) - \lambda_3(-\mu - \mu_0 - \gamma) \\ -\lambda_4' &= \lambda_4 \mu \end{aligned} \tag{13}$$

and with transversality conditions

$$\lambda_i = 0, \text{ for } i = 1, 2, 3, 4. \tag{14}$$

and the controls u^* satisfy the optimality condition

$$\begin{cases} u_1^* = \max \left\{ 0, \min \left(1, \frac{\lambda_1 \Lambda_h + \lambda_4 k E_e}{2 B_1} \right) \right\} \\ u_2^* = \max \left\{ 0, \min \left(1, \frac{\beta (\lambda_2 - \lambda_1) (E_e + I_e) S_e}{2 B_2} \right) \right\} \\ u_3^* = \max \left\{ 0, \min \left(1, \frac{\lambda_3 \delta E_e}{2 B_3} \right) \right\} \end{cases} \tag{15}$$

Proof: The governing equations of the adjoints variables are obtained by differentiation of the Hamiltonian function, evaluated at the optimal control. And with transversality conditions

$$\lambda_i = 0, \text{ for } i = 1, 2, 3 \tag{16}$$

On the interior of the control set, where $0 < u < 1$, we have

Hence, it is obtained (see Mohammed, Yahya and Farah 2014)

$$\begin{cases} u_1^* = \max \left\{ 0, \min \left(1, \frac{\lambda_1 \Lambda_h + \lambda_4 k E_e}{2 B_1} \right) \right\} \\ u_2^* = \max \left\{ 0, \min \left(1, \frac{\beta (\lambda_2 - \lambda_1) (E_e + I_e) S_e}{2 B_2} \right) \right\} \\ u_3^* = \max \left\{ 0, \min \left(1, \frac{\lambda_3 \delta E_e}{2 B_3} \right) \right\} \end{cases} \tag{17}$$

RESULTS AND DISCUSSION

Numerical Simulations

In this section, the numerical simulations are presented to illustrate the analytical results. Next, we examine numerically the effect of the optimal control strategies on the spread of involved in examination misconducts in a population.

Strategy A: Optimal use of rewards.

Strategy B: Optimal use of appropriate supervision.

Strategy C: Optimal use of imprisonment and expulsion.

Table 1: Description of variables for involved in examination misconducts model

Parameter	Description
S_e	Susceptible students
E_e	Exposed (lightly involved in examination misconducts) students
I_e	Infected (highly involved in examination misconducts) students
R_e	Removed (quitters) students

Table 2: Description of parameters for involved in examination misconducts model

Par.	Description	Est. Value
λ_h	Recruitment rate of students	0.05
β	Force of infection	0.23
μ	Natural death of students	0.0004
μ_0	Death due to imprisonment and expulsion.	0.05
γ	Rate of progression from highly involved in examination misconducts	0.04
δ	Rate of progression from lightly involved in examination misconducts	0.03
k	Rate of progression from lightly involved in examination misconducts students to quitters	0.09

Optimal use of the rewards (u_1)

With the control strategy, use of rewards (u_1) is used to optimize the objective functional J , while the control appropriate supervisions (u_2) and imprisonment/expulsion (u_3) are set to zero. In figure 1, the result shows a significant difference in the S_e and R_e with optimal control strategy compared to S_e and R_e without control. It was observed in figure 1(a) that the susceptible students S_e decrease as a result of control strategies against the increase in the uncontrolled case. In figure 1(b) similar situation was also observed in the case of removed (quitters).

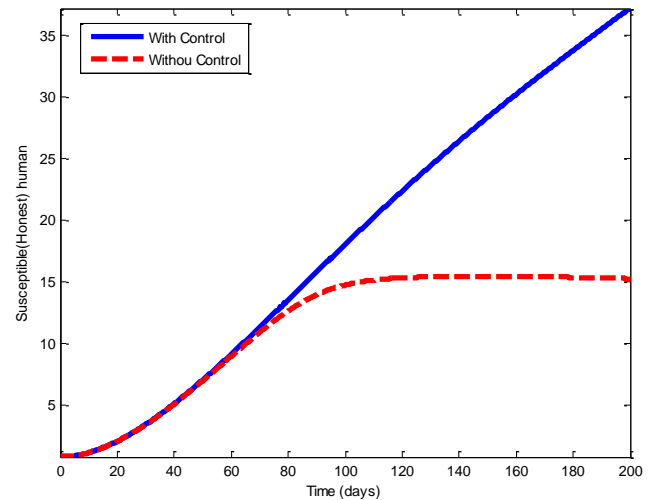


Figure 1 (a): Simulations showing effect of optimal rewards on recovered class to control on the spread of examination misconducts

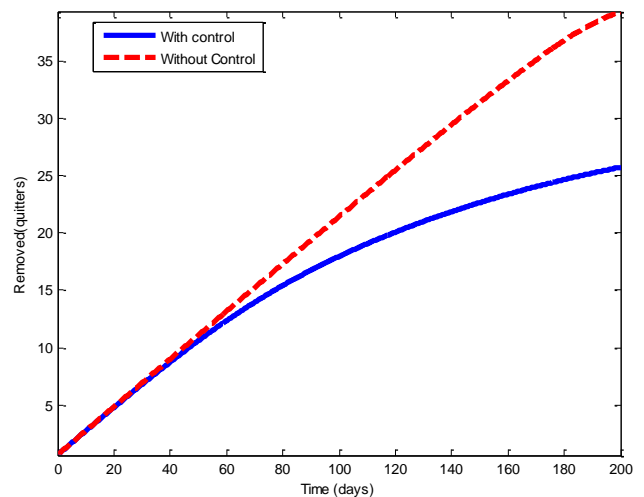


Figure (b): Simulations showing effect of optimal rewards on recovered class to control on the spread of examination misconducts.

Optimal use of the appropriate supervisions (u_2)

In this control strategy, use of appropriate supervisions (u_2) is used to optimize the objective functional J , while the control rewards (u_1) and imprisonment/expulsions (u_3) are set to zero. In figure 2, the result shows a significant difference in the E_e with optimal control strategy compared to E_e without control. It was observed in figure 2 that the exposed (lightly involved in examination misconducts) students E_e decrease as a result of control strategies against the increase in the uncontrolled case.

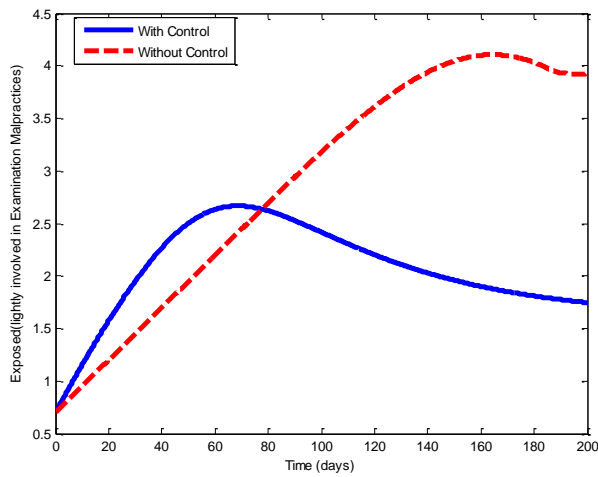


Figure 2: Simulations showing effect of optimal use of the appropriate supervision on the spread of examination misconduct.

Optimal Use of imprisonment/expulsion (u_3)

In this control strategy, use of imprisonment/expulsion (u_3) was used to optimize the objective functional J , while the control rewards (u_1) and appropriate supervisions (u_2) were set to zero. In figure 3, the result indicates a significant difference in the I_e with optimal control strategy compared to I_e without control. It was observed in figure 3 that the exposed (highly involved in examination misconducts) students I_e decrease as a result of control strategies against the increase in the uncontrolled case.

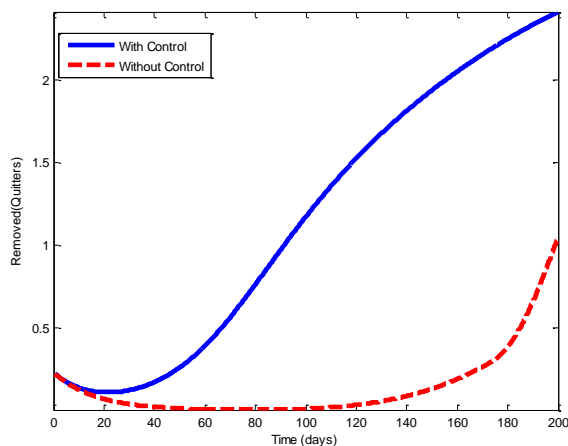


Figure 3: Simulations showing effect of optimal imprisonment/expulsion to control on the spread of examination misconducts

Conclusion

In the paper, a deterministic mathematical model for involvement in examination misconducts controls was developed. The model investigated the interaction of the susceptible students, exposed (lightly involved in examination misconducts students, infected (highly involved in examination misconducts) students and the removed (quitters). And, it was established that the model is locally asymptotically stable when $\mathfrak{R}_0 < 1$ and unstable for $\mathfrak{R}_0 > 1$. The numerical simulation results have indicated that the best control strategies for control of the misconduct are the three control strategies. However, the implication of using all the controls is that additional cost will be incurred. This was because; strategy A has a significant effect on this control of involved in examination misconduct. It could be concluded therefore, that to control the involvement in examination misconduct; the most cost-effective all of the strategy remained the use of rewards (strategy A).

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