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From heroin epidemics to methamphetamine epidemics: Modelling substance abuse in a South African province

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ABSTRACT

The global rise in the use of methamphetamine has been documented to have reached epidemic proportions. Researchers have focussed on the social implications of the epidemic. A typical drug use cycle consists of concealed drugs use after initiation, addiction, treatment-recovery-relapse cycle, whose dynamics are not well understood. The model by White and Comiskey [41], on heroin epidemics, treatment and ODE modelling, is modified to model the dynamics of methamphetamine use in a South African province. The analysis of the model is presented in terms of the methamphetamine epidemic threshold $\mathcal{R}_0$. It is shown that the model has multiple equilibria and using the center manifold theory, the model exhibits the phenomenon of backward bifurcation where a stable drug free equilibrium co-exists with a stable drug persistent equilibrium for a certain defined range of $\mathcal{R}_0$. The stabilities of the model equilibria are ascertained and persistence conditions established. Furthermore, numerical simulations are performed; these include fitting the model to the available data on the number of patients with methamphetamine problems. The implications of the results to drug policy, treatment and prevention are discussed.

1. Introduction

There has been a dramatic increase in treatment demand for drugs such as dagga, mandrax, cocaine, heroin and methamphetamine (MA) in the Western Cape Province (WCP) of South Africa in recent years. MA patients defined herein as drug users who used MA as a primary or secondary drug of abuse, increased from 121 to 376 patients from the second half of 2003 to the first half of 2004. More than 50% of the patients were under the age of 20 [33]. Drug abuse and the burden of drug use is also greater in the WCP when compared to other provinces in South Africa.

Methamphetamine, is a highly addictive stimulant, whose production and abuse has increased dramatically in South Africa, with similar trends having been observed in the United States during the past decade, see for instance [28], and the references cited there in. It is a cheap street drug with a variety of forms and street names. It is commonly known as "tik" in South Africa [31] and was introduced through gang culture in affected communities. The common effects of intoxication are increased energy and self-confidence, euphoria, heightened libido and appetite suppression. Non-drug users such as young girls are usually lured by its weight loss properties. Prolonged use is usually characterized by severe weight loss, mood swings, violent behavior and body organ disorders [24,28,33]. Morris and Parry [31], reported high rates of increase of HIV infections in communities with high MA use. In the 2005 antenatal survey, the WCP had the highest increase of new HIV infections, from 13.1% in 2003 to 15.7% in 2005, compared to other provinces. MA use has been linked to risky sexual behavior and sexually transmitted infections [40]. Thus, MA use has immense public health implications.

It is against this background and the implications of MA abuse to public health in the WCP, that we extend the model on heroine epidemics by White and Comiskey [41] to qualitatively study the dynamics of MA use in the WCP, with the aim of providing a predictive tool on the behavior of different classes of drug users.

White and Comiskey [41], analyzed a model for heroin users which was revisited by Mulone and Straughan [32]. In this paper, the class of drug users not on treatment in [41] is divided into two classes: firstly, a class of drug users who are allowed to pass through a period of concealed drug use at the beginning (light drug users). It is at this stage that one can easily stop and recover from drug use. Secondly, a class of hard drug users who are addicted. The period of concealed drug use is followed by the problematic phase of addiction. Continued use of drugs usually results in criminal, health and social problems that are identifiable and it is at this stage that assistance in the form of treatment is instituted. In [41], individuals under treatment are allowed to relapse to the class of

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untreated drug users. We allow for the recovery of those under treatment into a class of the recovered. This is because treatment for drug users is currently restricted to treatment centers and individuals are released from treatment centers when they have recovered. So we shall assume that a relapse can only occur after individuals have recovered. We assume that upon relapse, an individual is more likely to become a hard drug user again than being a light drug user due to familiarity in drug use. We also assume that there are no fast progressors, i.e. individuals who immediately become hard drug users after an initiation. We however acknowledge that patients under treatment can be 'inpatients' or 'out-patients'. In this paper we assume that treatment on an 'inpatients' basis.

While the epidemic presents a sizeable challenge, interventions have been put in place. They include reducing the supply of drugs to the communities, promoting intervention programs associated with behavior change and improving access to quality treatment. In order to model aspects related to behavior change we include the exponential function $e^{-m\delta I_2}$ in the incidence function. The function models behavior change induced by the adverse effects of addiction related to mortality in this case. The same function has been used by a number of researchers to model behavior change and the impact of information campaigns, see for instance [9,2]. The effects or impact of behavior change associated with the mortality of individuals in the I_2 class is measured by m. Firstly, the model analysis involves a consideration of the proposed model in the absence of behavior change. Secondly, we incorporate behavior change in the model. Inclusion of behavior change increases the non-linearity of the incidence function and thus we will resort to numerical simulations.

The paper is arranged as follows: in the next section we present the model formulation, followed by the model analysis in Section 3. Numerical simulations are presented in Section 4 and a discussion in Section 5 concludes the paper.

2. The model

As in [41], based on the premise that the evolution of MA use can be mirrored to the evolution of a disease, the model monitors the change of the sub-populations (classes) of susceptible individuals at risk of using MA $S(t)$, light MA users $I_1(t)$, hard MA users $I_2(t)$, clients of health care services in treatment $T(t)$ and recovered individuals $R(t)$. The total population is thus given by

$$N(t) = S(t) + I_1(t) + I_2(t) + T(t) + R(t).$$

Individuals under treatment use drugs but do not 'infect' non-users of drugs. Only light and hard MA users are capable of recruiting non-users and cause a relapse. The population is assumed to be large enough to be modeled deterministically. We also assume homogeneous mixing so that those at risk of drug use are equally susceptible. In practice, susceptibility to drug use varies. This is due to differences in environmental, behavioral and social factors. Individuals at risk of using MA can become light users through effective contacts with drug users not on treatment. An effective contact is the product of the average number of contacts per unit time c, and the probability that a contact will result in a non-MA users becoming a user. This process mirrors what happens during the spread of infections such as sexually transmitted infections (STIs). For STIs, upon contact with an infected individual, a non-infected individual can be infected at a certain probability. Similar assumptions have been made in mathematical models for smoking dynamics, in which the acquisition of smoking habits is analogous to the spread of a disease [37]. The generation of new drug users is often affected by other factors apart from individual contacts. The process is thus more complex than described here. For instance, recruitment into drug use can be by self-conversion. Drug lords are also key to the generation of new drug users and this forms part of our current research considerations. Such forms of recruitment are beyond the scope of this paper. Individuals move from one class to the other as their status with regards to MA use changes. The possible changes in the life of a MA user can be tracked by the schematic representation in Fig. 1 and the parameters are defined in Table 1.

Based on Fig. 1, the model is mathematically described by the following set of equations;

$$\frac{dS}{dt} = \Lambda - \lambda S - \mu S, \quad (1)$$

$$\frac{dI_1}{dt} = \lambda S - (\mu + k + \gamma_1)I_1, \quad (2)$$

$$\frac{dI_2}{dt} = kI_1 + r\lambda R - (\mu + \sigma + \delta)I_2, \quad (3)$$

$$\frac{dT}{dt} = \sigma I_2 - (\mu + \gamma_2)T, \quad (4)$$

$$\frac{dR}{dt} = \gamma_1 I_1 + \gamma_2 T - r\lambda R - \mu R, \quad (5)$$

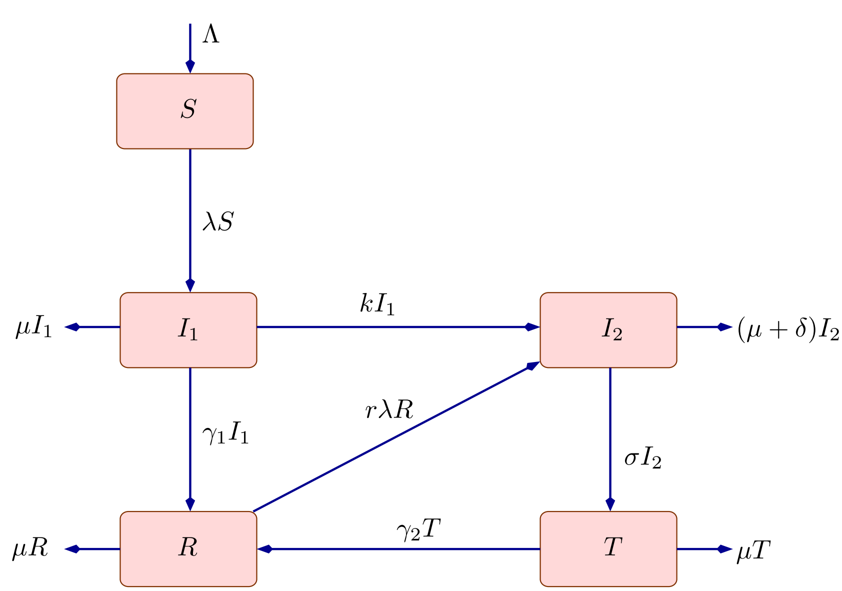

Fig. 1. A compartmental representation of the epidemic of methamphetamine use.