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The role of dynamic modelling in drug abuse epidemiology

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ABSTRACT

Policy makers need information to describe and understand a situation involving problematic drug use, follow trends over time, design appropriate interventions and evaluate the results of the action taken. Monitoring drug use and drug problems involves complex information, based mostly on observational data and epidemiological indicators. Dynamic models can be used to generate estimates where data are sparse or to verify hypotheses or predict trends by means of "what if" scenario analyses. The simple act of building a model forces a researcher to make explicit statements about the process being studied, which usually leads to discussion and improved insight. The models that can be used effectively in the drug field are essentially models of epidemics that describe the spread of a disease in a population in order to provide evidence for public health-oriented interventions and policies. One such model proposed recently to reflect the spread of drug use in a population is described in the present article and used to demonstrate the potential of that approach.

Keywords: drug use; epidemics; compartmental modelling; scenario analysis; drug policy.

Introduction

When defined in general terms the needs of a policy maker seem remarkably clear: it is necessary to describe and understand a situation involving problematic drug use and follow trends over time, design appropriate interventions and evaluate the results of the action taken. Monitoring drug use and drug problems involves complex information, based mostly on epidemiological indicators derived from incomplete data.

The available data are incomplete because drug abuse is generally stigmatized and hidden, and trafficking in and possession of drugs are criminal offences in most countries. Consequently, there have been varying degrees of under reporting when standard epidemiological survey techniques such as household surveys of drug abuse or direct enumeration of cases (case finding) have been used. It is

therefore necessary to develop methods that allow the extent of the phenomenon to be estimated and the dynamics to be described from observational secondary data on drug abuse that are available in various forms. Secondary data can be defined as existing statistical and documentary information that is routinely collected and readily available, such as data concerning treatment presentations, drug seizures, infectious disease indicators or drug-related deaths. Estimation techniques refer mostly to models and methodologies used to estimate the extent and the dynamics of drug abuse in a community or at the regional or national level, or both, based on various observed phenomena and information received on a target population [1, 2].

This is achieved in general by describing the components of the process and the relationships between them in a formal or quantitative way, in particular by means of mathematical models. By manipulating or experimenting with the model, conclusions can be drawn that cannot be found by direct observation of the "real" process. Mathematical models can even aid in the design and choice of appropriate responses by providing a means of integrating data from different sources, describing a process to increase understanding and simulating policy experiments that are not possible in real life [3]. The models that can be used in the drug field are essentially dynamic models of epidemics aimed at describing the spread of a disease in a community.

There are similarities between the spread of drug use, in particular the spread of use of addictive drugs such as heroin, and that of infectious diseases [4-6]. The use of drugs is communicated, obviously not as an organic agent, but as a kind of "innovative" social practice or custom, and not to everyone but only to those who, for whatever reason, are not immune (prone individuals). Once the contagious nature of drug use is accepted, the epidemiological concepts of "incidence" (the rate of new cases occurring within a certain period of time) and "prevalence" (the number of cases at a particular time) are operationally valuable in studying illegal drug use. Unfortunately, as already mentioned, the hidden population of users cannot be properly studied by standard statistical methods. Mathematical models, in particular compartmental models, are therefore useful for studying problem drug use [2, 7-10]. Such models enable prevalence and incidence to be estimated, scenario analyses to be carried out and trends to be predicted, on the basis of indirect indicators such as therapy presentations, incarcerations and so forth.

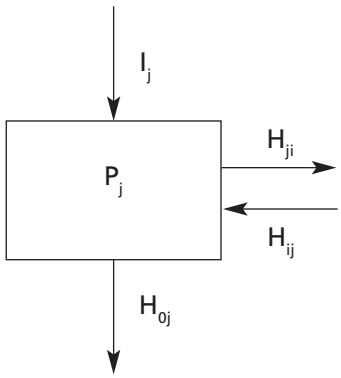
Compartmental models of epidemics

Compartmental models are a well-established and powerful mathematical tool for modelling the spread of "diseases" in a population [11]. They provide a framework in which numbers of people in different "compartments" (each one homogeneous with respect to some specified characteristic) and the relationships between such compartments, which model the dynamics of the population, can be described in mathematical terms. Two main types of model have commonly been used to describe the spread of diseases: deterministic models, expressed in terms of systems of differential equations, and stochastic models, expressed in terms of

stochastic equations or processes. Both assume that the population can be split into compartments that can be considered homogeneous with respect to a particular characteristic. Once the population has been split into compartments, it is easy to use suitable equations to describe mathematically how the size of the compartments will change over time, according to the basic hypotheses of the model describing the dynamics of the population under study. The result obtained from the model is usually the number of people in a specific compartment at a specific time (prevalence) or the number of people moving to or from, or moving to and from, a given compartment over a specified period of time (incidence).

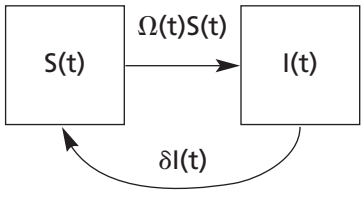
A simple general scheme of compartmental models of epidemics is shown in figure I. In the following section one such model is described and used to demonstrate the potential of the methodology in drug abuse epidemiology.

Figure I. Diagram of general compartmental models of epidemics



In general, a compartment is represented by a rectangle containing a capital letter, which represents the "level" of the compartment, that is, a state variable counting the number of individuals or the prevalence in the compartment, standardized if necessary

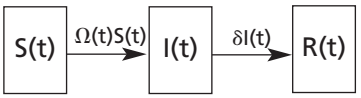
The arrows represent movement from or into the compartment. The inflows can originate either from another compartment (in which case the pair of ordered subscripts of the transition rate shown near the arrow indicate the originating and destination compartments), or from outside the system (in which case often only one subscript appears, or the originating compartment is indicated by 0). The outflow transition rates are indicated in the same way.



Two basic types of model can be used: S-I-S and S-I-R. S-I-S models can be used to represent situations in which susceptible individuals pass through a phase of infection and then recover, becoming again susceptible. S(t) is the state variable representing the susceptible population at time t, whereas I(t) is the state variable representing the infectious population.

Further transitions may take into account the possibility of death or any other relevant possibility.

Figure I (*continued)*



S-I-R models can be used to represent situations in which susceptible individuals pass through a phase of infectivity and then recover, becoming immune. S(t) is the state variable representing the susceptible population at time t, whereas I(t) is the state variable representing the infectious population and R(t) the recovered population.

Further transitions may take into account the possibility of death or any other relevant possibility.

A model for an epidemic of drug use

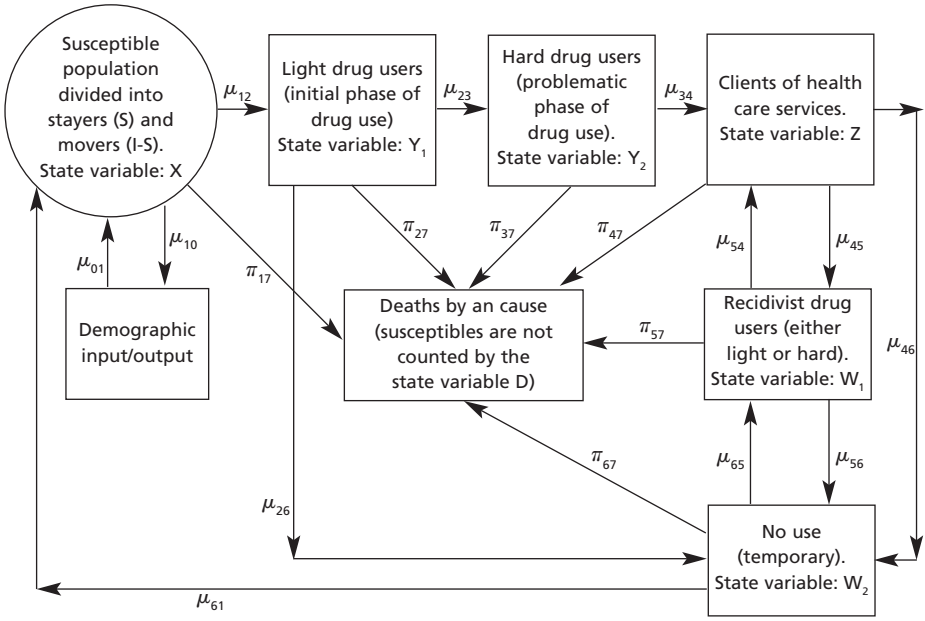
Figure II describes the main features of a model that was recently proposed [9, 10]. The model is of the "mover-stayer" type and allows for heterogeneous risk behaviour among the susceptibles. Such models consider the susceptible population as subdivided into two groups: the group of "stayers", that is, the group of individuals who, owing to their "prudent" behaviour, are considered not to be at risk of "infection" (these models are suitable for making scenario analyses in order to assess the impact of various proportions of vaccinated persons on the probability of extinction of a given epidemic) and the group of "movers", who are individuals at risk of infection. Owing to the interactions between infectious individuals (in the present case these are the problem drug users who are also pushers)[1] and the susceptibles, or owing to the pressure of the black market on the susceptibles, some of these may pass to the drug user compartments and begin a "drug user career". Like the model proposed by Behrens and others [7], the present model comprises two different stages of hidden drug use. The first (light use) stage is the initial, or non-problematic, stage of drug use, then light drug users can either stop using drugs or pass to hard drug use (or death). The other arrows represent the other possible transitions in a drug user career.

Using the flow chart (figure II), it is straightforward to write the equations of the model either in the form of deterministic (continuous or discrete) equations or in the form of stochastic (continuous or discrete) equations. Only the very general features of the model and policy-relevant conclusions are considered in the present article; the discrete stochastic equations are reported elsewhere [10]. The model is a combination of an S-I-S and an S-I-R model, with the second

[1]The surveys conducted among military conscripts reported in the annual report on the state of the drug problem in Italy for the year 1999 revealed that the two most-mentioned reasons for drug use were curiosity (over 40 per cent) and peer group pressure (over 30 per cent).

dominating. Thus, according to the general mathematical theory of epidemic models reported in Iannelli [11], it follows that an epidemic phase followed by an endemic phase is always obtained.

Figure II. A simple "mover-stayer" model for an epidemic of drug use



Using the simulation procedure [9, 10], a scenario analysis can be carried out to evaluate the influence of the various parameters on the course of the epidemic. Scenario analyses can also be used to evaluate numerically the impact of the various kinds of intervention (primary and secondary prevention, harm reduction and so forth).The results of the various scenario analyses [9, 10] show that the bigger the core group of "at risk" susceptibles, the faster the spread of the epidemic and the higher the prevalence and incidence curves, while the influence of the parameter that measures the pressure of the black market appears to be less important.

Some general qualitative results

Some qualitative analytical results have been obtained and scenario analyses carried out on the basis of various hypotheses on the parameter values and have been discussed elsewhere [9, 10]. The simulation procedure used to obtain the scenario analyses is written in S-plus. All the parameters can be modified at the beginning of each run and the total simulation time, which is measured in weeks, can be

chosen. The standard output comprises graphs of the prevalence curves in each compartment and of the incidence curves of major interest. The output also comprises the curves representing the main macroepidemic indicators such as the epidemic/endemic indicator, which is negative only during the epidemic phase, and the impact indicators related to primary and secondary prevention interventions and harm reduction, measuring the expected difference of the onset incidence (transitions from X to Y1) when the intervention is implemented compared with the basic situation (no intervention).

The numerical results reported in graphic form in figures III-IX enable the main features of the model to be presented. These results were obtained on the basis of the parameter values estimated for Italy. The first "epidemic wave" (figure III) relates to the incidence of light use, which generates the prevalence of light use, and (figure IV) by a transformation that produces a deformed wave. There follows a second incidence wave (figure V), of hard drug use, generating the second prevalence wave (figure VI), of hard drug use and so on for other compartments, such as therapy, recidivist use and so forth, which are not presented in figures III-IX. Incidence and prevalence per one million inhabitants are reported.

Figure III. Incidence curve from susceptibles to light users

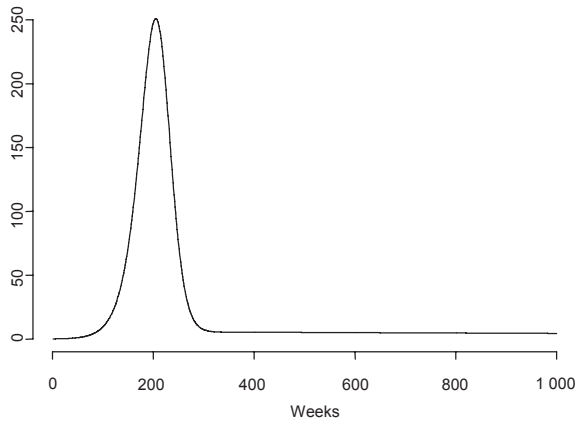


Figure IV. Prevalence curve of light users

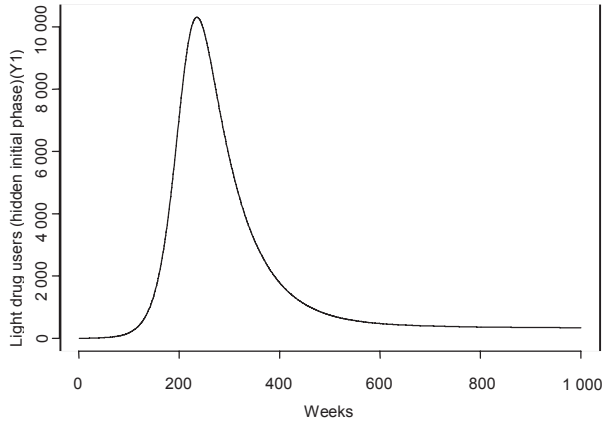


Figure V. Incidence curve from light users to hard users

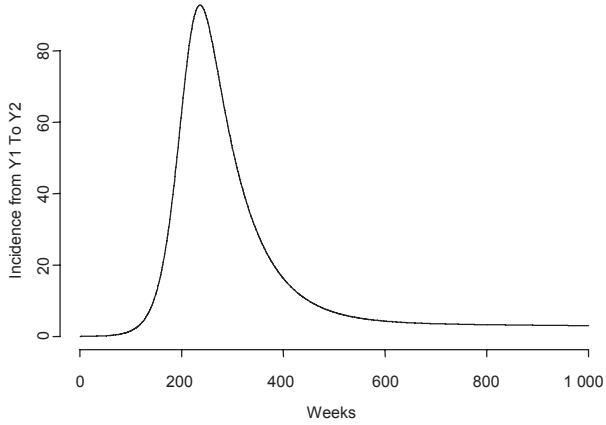


Figure VI. Prevalence curve of hard users

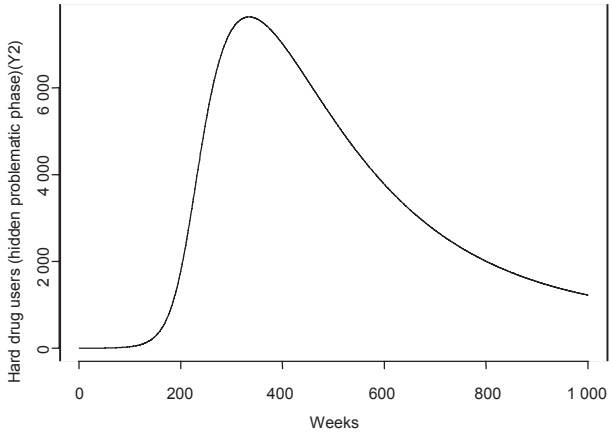


Figure VII. Epidemic endemic indicator

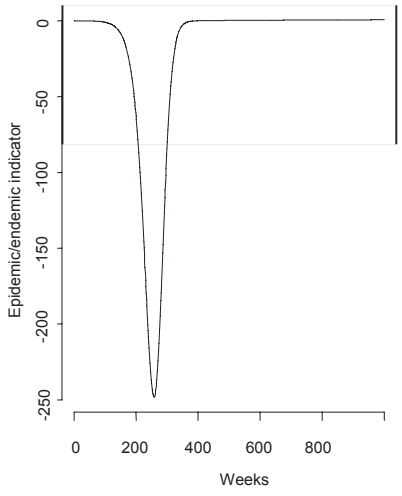


Figure VIII. Expected impact of a primary prevention intervention

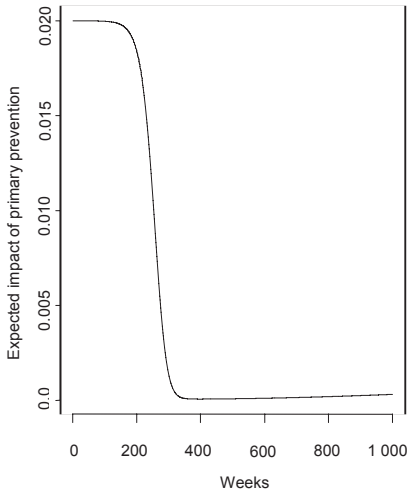
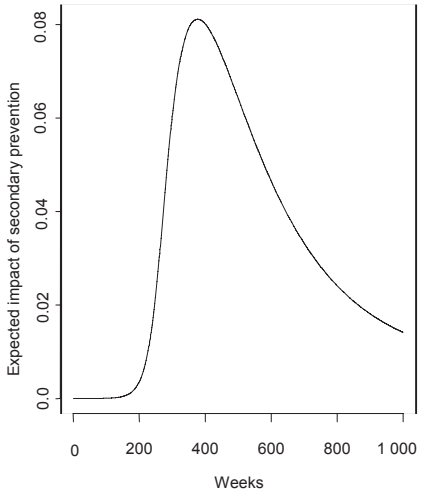


Figure IX. Expected impact of a secondary prevention intervention



The last three curves, which represent the behaviours of relevant macroindicators, enable some observations to be made that may be useful to policy makers. In figure VII, the behaviour of the epidemic/endemic indicator shows that the epidemic spreads fast and is then followed by the endemic phase, starting about seven years after the outbreak; in figure VIII, primary prevention interventions have a higher impact on the epidemic at the beginning, then the impact decreases rapidly; in figure IX, as might be expected, secondary prevention interventions have a higher impact when the prevalence of drug use is higher, but the efficiency decreases during the endemic phase.

These qualitative observations may be extended to any epidemic model similar to that presented, for any disease, and may therefore also apply to any infectious disease epidemic among drug users and, in particular, among injecting drug users, which spreads both by sharing needles and by sexual intercourse, such as the human immunodeficiency virus (HIV), hepatitis B and hepatitis C.

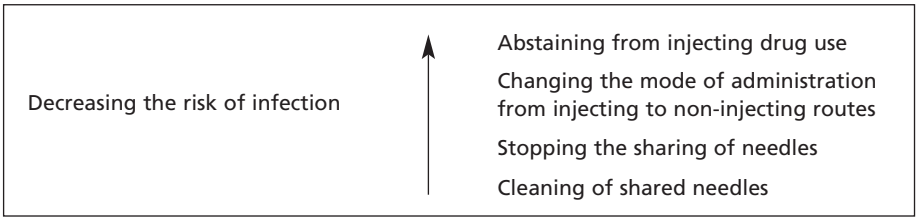
Conclusion

In the present article, a compartmental model for reproducing an epidemic of problematic drug use has been presented. Qualitative and quantitative analyses (by means of simulation) have been presented to demonstrate the potential usefulness of the model for decision makers. The quantitative analyses ("what if" scenarios) have been developed on the basis of knowledge gained from the heroin epidemic of the last 20 years in Italy, which enabled several parameter values to be derived from various epidemiological and statistical studies that were already available. The results obtained, from both the qualitative and the quantitative analyses, apply to any kind of epidemic of drug use, even involving new drugs, at least from a qualitative point of view. In particular, the qualitative evaluation of the effectiveness of different types of intervention over the course of the epidemic is valid for any epidemic of problematic drug use; for example, the indications arising from the behaviour of the epidemic/endemic indicator, which changes abruptly to coincide with changes in the efficacy of policy interventions (notably prevention), can be considered. This suggests that policy makers should monitor such parameters, which are not directly observable, using indirect estimates, such as onset incidence estimates obtained by various estimation methods or survey data [12, 13]. In fact, the epidemic part of the indicator is essentially based on the incidence of new use. Consequently, decision makers should put in place real-time monitoring systems to estimate onset incidence.

The qualitative results obtained also enable the possible impact of harm-reduction interventions to be indirectly evaluated. Harm reduction is a public health approach that gives priority to reducing the adverse consequences of drug use for the individual, the community and society, rather than to eliminating drug use or ensuring abstinence. Although the aim is still to reduce drug use in general, emphasis is placed on the elimination of the potential harmful effects of drug-taking behaviour.

With regard to HIV or hepatitis, for example, a harm-reduction strategy will first try to reduce the transmission of infections by means of the cleaning of shared injecting equipment or the cessation of that sharing, rather than by means of promoting abstention from drug use (figure X). Achieving those immediate and realistic goals is usually viewed as a first step towards risk-free use; abstinence may be considered a final aim. It follows that a harm-reduction intervention aimed at reducing the transmission of infection can be viewed as a secondary intervention with respect to the epidemic of drug use, but as a primary prevention intervention with respect to infection.

Figure X. Hierarchy of intervention goals for reducing the transmission of HIV



This kind of intervention therefore has a high impact with respect to the onset incidence of injecting drug use when the prevalence of injecting drug users is high, but it can really prevent infectious diseases only if applied at the very beginning of the epidemic of injecting drug use. It can therefore be concluded that harm-reduction measures aimed at preventing the spread of infectious diseases among injecting drug users should be taken as early as possible. The empirical evidence from the various European Union countries where such measures have been taken confirms these general qualitative results obtained a priori on the basis of the dynamic model [14].

Finally, the model demonstrates that the spread of the infectious disease epidemic among injecting drug users is related for the most part to the hidden part of the drug user's career (compartments Y1 and Y2 of figure II). This suggests that the objective of interventions should be to reduce the duration of that period, which is called the latency period. According to analyses carried out in several European Union countries, the latency period appears to be remarkably similar in different cities, with a median of between four and six years and an average of between five and seven years [12, 13]. However, the true lapse appears to be much longer than this for young drug users, which implies a need for specific interventions aimed at young drug users in order to reduce their latency period and prevent the spread of infectious diseases.

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