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Role of media coverage and delay in controlling infectious diseases: A mathematical model

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ABSTRACT

The aim of this paper is to investigate the effect of awareness coverage and delay in controlling infectious diseases. We formulate an SIS model considering individuals' behavioral changes due to the influences of media coverage and divide the susceptible class into two subclasses: aware susceptible and unaware susceptible. Other model variables are infected human and media campaign. It is assumed that the rate of becoming aware (unaware), from unaware to aware susceptible human (from aware to unaware susceptible human), is a function of media campaign. A time delay is considered for the time that is taken by an unaware (aware) susceptible individual to become aware (unaware). An additional time delay is considered due to the time lag needed in organising awareness campaigns. The model exhibits two equilibria: the disease-free equilibrium and the endemic equilibrium. The disease-free equilibrium is stable if the basic reproduction number is smaller than unity and the endemic equilibrium exhibits a Hopf-bifurcation, in both delayed and non-delayed system, whenever it exists. Analytical and numerical results prove the significance of awareness and delay on the prevalence of infectious diseases.

1. Introduction

Infectious diseases are major nuisances to mankind. They cause mortality, disability, as well as social and economic disturbance for society. Pneumonia, Tuberculosis (TB), Diarrheal diseases (Cholera), Malaria, Measles and more recently HIV/AIDS etc. are the major deadly infectious diseases. Including premature deaths and deaths of young children, in developing countries approximately 11 million people die each year due to infectious diseases [1–4].

At the beginning of an epidemic outbreak, the initial step to try to control it, is to make people aware of the disease through the media and to let them know preventive measures that can be adopted. The media coverage is obviously not the most important factor responsible for fighting the transmission of the infectious disease, but it is a very important issue which has to be considered seriously. In the case of a large number of infected cases, on one hand, media coverage may cause panic in the society, while on the other hand, it can certainly reduce the opportunity of contact among the alerted susceptible populations, which in turn helps to control the transmission probability and prevent the disease from further spreading [5].

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It is well known that some diseases upon recovery give permanent immunity, e.g. influenza, measles, chickenpox, while for other ones the immunity is only temporary, for instance gonorrhea, meningitis, tuberculosis. For a third class of illnesses, no vaccination is yet available: malaria, dengue, chikungunya, AIDS. In the latter case, the best control at the moment is to prevent people to become infected. This can be obtained for instance by suitable campaigns through the media, [6,7].

Disease propagation in an epidemic outbreak is heavily dependent on the people's behavior. In Bari, South-East Italy, the cholera outbreak of 1973 has been curbed within a few days because the local individuals implemented severe measures to avoid its further spread. This gave rise to one of the now classical models, the so-called Capasso–Serio epidemic model, [8], which incorporates the individual behavior in the Monod–Haldane functional response. The infection rate decreases with an increasing number of reported infected, as susceptibles take stricter measures to avoid to be infected themselves, a fact that is well known in the literature, [6,9,10]. The essential mean that contributed to this change in behavior in the cholera epidemics was the information that media were providing. Indeed, during the initial phase of the epidemics, most people and public mass media are in general unaware of the disease, but as the awareness of it disseminates, people respond and eventually change their behavior to reduce their susceptibility. Media familiarizes people with the diseases and the possible preventive means to avoid becoming infected, e.g. social distancing, wearing protective masks, practice of better hygiene, use of preventive medicaments, vaccination, voluntary quarantine. People aware of the danger of the epidemic spread adopt practices to try to minimize their exposure to contagion, a fact that may deeply influence the epidemic pattern, [11,12].

Recent investigations have begun to introduce explicitly the role that media campaigns possess to influence people's behavior during epidemics outbreaks, see for instance [13–15]. In the mathematical epidemic models, this in general is obtained by partitioning the whole susceptible population among aware people and those that are not knowledgeable of the proper ways to reduce the risks of infection, [16]. However, because of the initial lag in realizing the danger of the epidemics spread and render it public, generally the response from the people is not immediate. This fact should be taken into consideration for a proper modeling of the situation. A formulation that suitably incorporates time delays becomes imperative in this situation. Models of this kind have been considered in the literature, [17–20]. Among the findings, the time delay between the advertising campaigns and the moment in which people start to act deeply influences the endemic equilibrium stability leading to periodic oscillations when the basic reproduction number exceeds unity. The similar delay in reporting the epidemic outbreak has been considered in [21], while a modification with the assumption that the growth rate of aware people increases at a rate proportional to the infective population is presented in [22]. Two delays, one in reporting of the infected cases, and the other due to the fading away of disease awareness after a fixed period of time are studied in [14], with the findings that an increase in the duration of awareness reduces the equilibrium level of infected. Both time delays can destabilize the endemic equilibrium and trigger persistent oscillations.

In this study, a mathematical model is proposed to investigate the change in prevalence of an infectious disease when an awareness program through the media is employed. Our main aim is the study of the impact on the epidemic outbreak of the combined action of the awareness program and the time delays. The former is not present in [21]. In [19] an SIRS model is presented with an infected-dependent rate in the transmission process, but no explicit modelization of the media coverage is included. In [17] there is only one delay, also in the infected reports in the media advertisements. Note also that awareness recruitments are not constant, but rather assumed to depend on the media campaigns, $M(t)$ following an explicit saturation function. For us instead, this functional dependence is not only nonlinear, as for instance in [22], but expressed via a generic, monotonically increasing function f. Both these aspects are more realistic because in reality it is difficult to properly estimate these behavioral rates. A model closer to ours is presented in [14]. The functional responses for the media campaign are assumed of specific Holling type II form, for recruitment of aware people, while we generalize it through the generic function f bearing similar mathematical properties. Instead, a broader view is taken in [14] as far as the effect of the advertisement has on the contact rate, which is expressed by a hyperbola tending to vanish when M becomes large. In [11], the authors consider the levels of human awareness to model the effect of awareness and a time delay is introduced to take into account the time needed by unaware people to become aware. They have shown the existence of a Hopf bifurcation when the time delay parameter crosses a critical value. In the model proposed here, we simply take this contact rate constant. Finally, the fading away of implementing the safety measures occurs here via the generic nonlinear monotonically decreasing function G instead than at a constant rate. There are two delays also in [14], one for the time to implement the preventive measures, while the other one involves memory fading away. In our case instead, two time delays are also considered. The first one accounts for the time that is taken by unaware (aware) susceptible individuals to become aware (unaware). The second one is considered for the organisation and implementation of awareness campaigns. The endemic equilibrium exhibits a Hopf-bifurcation, in both delayed and non-delayed system.

The paper is organized as follows. The model is described next, followed in Section 3 by the analysis of the system with no delay. Delays are treated in the subsequent Section while Section 5 contains the numerical experiments. A final discussion concludes the paper.

2. The mathematical model

Let $S(t)$ and $I(t)$ be the density of the susceptible and infected populations respectively at time t. Further, the total susceptible population is divided into two subclasses: the susceptible population unaware of the disease fighting means, S_u and the aware susceptible population S_a. Here we stress that “aware” does not mean “informed” of the existence of the epidemics, but also knowledgeable of ways of avoiding disease propagation and further implementing these prevention mechanisms.