Chapter 10
Optimal Choice of Vaccination Scheduling in a Population Composed of Two Groups

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ABSTRACT

In this chapter, the authors present a simple model to determine the optimal choice of vaccination scheduling for a society composed of two groups of individuals in order to minimize the economic loss only, assuming herd immunity. First, a simple classical SIR model is presented to form the basis of the analysis; second, the model is revised to include the effects of vaccination which in turn will be extended to include two heterogeneous groups of individuals forming a society. The solutions of relevant differential equations will then be used to calculate the total economic cost of each scenario presented.

INTRODUCTION

COVID-19 pandemic has and still is costing many lives and economic losses for almost all nations. It seems that vaccination will be an efficient intervention strategy in fighting this pandemic. Fortunately, several vaccines have been developed and being administered in many nations. Some of these vaccines have been approved by World Health Organization (WHO) and European Medicines Agency (EMA) and many are under review by both of these organizations. Comirnaty and Pfizer-BioNTech vaccines have been approved for the prevention of disease in individuals 16 years of age and older. The statistics on the efficacy of the vaccines are different also. The information on the efficacy of vaccines is reported in detail in WHO and Yalemedecine websites in detail. However, there is no definite information on the duration of the efficacy of these vaccines. Some countries are already administering the third shots of these vaccines for some age groups.

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The results of vaccination efforts have certainly been good with varying degrees of impact on controlling the Corona virus with no definite success in any country. Almost all governments are struggling to minimize the economic impact of the disease by vaccinating their populations as quickly as they can and by taking other preventive measures. The new types (variants) of the virus are making the fight against the virus very difficult also. The relevant drug companies are working diligently to create new vaccines which will be effective against the new variants. The efficacy of the new vaccines remains to be determined as the statistics become more readily available.

The drug companies are also frantically working on new drugs for the virus. So far, there is no drug which cures this disease. Therefore, vaccinating the populations as quickly as possible remains the most effective method to control the disease other than preventive measures like wearing a mask, keeping the distance, and paying out most attention to hygiene.

The rule of vaccination in all countries was to vaccinate starting with older persons, persons with underlying diseases, health workers, and public servants. This is a moral approach to vaccine scheduling of populations as saving lives is the most important priority.

In this chapter, the authors present a model to determine the optimal choice of vaccination scheduling for a society composed of two groups of individuals in order to minimize the economic loss only, assuming herd immunity. To do this, the classical SIR model is introduced to form the basis of the analysis. The model is then revised to include the effects of vaccination which in turn is extended to include two groups of population. Subsequently, the solutions of relevant differential equations will be used to calculate the total economic cost.

BACKGROUND: THE CLASSICAL SIR-MODEL AND VACCINATION

The classical SIR model is proposed by Kermack and McKendrick (1927, 1932, 1933), which was one of the first formulations of a mathematical theory of epidemiology based on compartmental models. It is worth to note that the foundations of the entire such approach to epidemiology were laid, not by mathematicians, but by public health physicians such as Sir R.A. Ross, W.H. Hamer, A.G. McKendrick, and W.O. Kermack between 1900 and 1935 (Brauer, 2017).

In the canonical model (Murray, 1989; Anderson & May, 1991; Diekmann & Heesterbeek, 2000; Brauer & Castillo, 2000), a population of total size *N* is divided into three groups of individuals: (1) the susceptible *S* -- those who are not (yet) infected; (2) those who are infected and can spread the disease by contact with susceptibles; (3) the recovered *R* -- those who have been infected, then recovered and become immune for life, and do not spread infection. Their joint dynamics are modelled by the following system of ordinary differential equations:

$$
\begin{aligned}
\dot{S}(t) &= -\beta S(t) I(t) \\
\dot{I}(t) &= \beta S(t) I(t) - \gamma I(t), \\
\dot{R}(t) &= \gamma I(t)
\end{aligned}
$$

where β is the transmission rate of the disease (or the probability of getting infected), γ is the rate at which the infected becomes recovered and immune for life. The initial population is given by N(*0*)=