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Game Theory : A Case of Infectious Diseases

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ABSTRACT

Game theory is a mathematical model which deals with interactions between various entities by analyzing the strategies and choices. In today's world, Game Theory is being extensively used in fields like computer science, economics, sociology, political science, and so on, due to its versatile nature and applications in numerous conflicts and problems. The application of game theory has been extended to real life problems also due to its versatility and robustness. In this research, various game theory methodologies applied during pandemic was reviewed. Various aspects of these methodologies were highlighted such as methods applied, description, expected result and limitation. This research will act as a reliable and efficient way of understanding the concept of game theory and its application in combating infectious diseases, analyze and eventually understand different strategic scenarios. The main importance of game theory is to formulate the alternative strategy to compete with one another and in the same sense it is an essential tool for decision making process according to fluctuations in relevant contents. These reviewed methodologies would be further categorized into prevent, control or both based on the application they favour most.

Keywords : Game Theory, Epidemiology, Pandemic, Healthcare

I. INTRODUCTION

1.0 Background to the Study

Epidemiology as a branch of medical science dealing with the incidence, distribution, and control of diseases in a population, with the aim of identifying factors that give rise to their recurrent occurrences. The advent and global spread of recurrent pandemics and severe modern epidemics have become serious threats to mankind. Therefore, understanding and curbing the transmission of infectious disease is treated with utmost concern for our society. Emerging infectious diseases have disturbing negative impacts on public health and imposes a great financial burden on the community. Thus, it is of great importance to evaluate the potential methods for controlling the outbreak of these epidemic diseases (Muntasir, Ariful, & Jun, 2020). Currently, mathematical modeling has become an important tool in analyzing the spread and control of infectious diseases, owing to key factors governing the development of a disease, such as transmission and recovery rates that help to predict how the disease will spread over time. The quarantine of suspected susceptible or vaccinated individuals and the isolation of symptomatic infected individuals are two of the most common intervention measures for combating the spread of communicable emerging or re-emerging diseases. Implementing such measures, however, incurs a partial cost to every single individual living in the society. Game theory as an autonomous discipline that is used in applied mathematics, economics, engineering, computer science and philosophy (amongst other disciplines); is the scientific study of strategy and conflict, in which the success of a choice depends on the choice of others. Approaches from game theory and mathematical economics have been demonstrated to be a powerful modeling tool, applied to understanding, controlling, and efficiently design dynamic, complex networks. Game theory provides a good starting point for computer scientists in their endeavor to understand selfish rational behavior in complex networks with many agents (players). Such scenarios are readily modeled using techniques from game theory, where players with potentially conflicting goals participate in a common setting with well-prescribed interactions (Marios, Vicky, & Paul, 2007). Its initial development was in economics to understand a large collection of economic behaviours, including behaviours of firms, markets and consumers. Attempts has been made in using Game theory to develop theories of ethical or normative behaviour as well. Also, in economics and philosophy, game theory has been applied to help in the understanding of rational behaviour (Bellal, 2016). In other words, it is the analysis (using mathematical reasoning) of a conflict of interest to find the optimal choices for reaching the desired outcome, under given conditions.

1.1 Problem Statement

The 20th century has seen tremendous achievements in infectious disease prevention, owing to the development of effective preventive vaccines, often far less costly than treatment. Still, the preference between prevention and treatment persists; as the prevention of treatable infectious diseases still poses challenges for public health authorities (Gérvas, Starfield, & Heath, 2008). Faced with the risk of infection, individuals may decide on prevention or treatment if they are infected. Whereas treatment is generally well accepted by infected individuals, prevention may be widely acceptable. A wide range of parametric conditions to suppress the disease spreading severity amid those individuals who primarily took the vaccination as a pre-emptive provision. However, due to the transient effect of vaccination and the widespread occurrence of epidemic outbreaks, there is an increasing need to seek for more sustainable approaches to protect the global community from viral diseases (Muntasir, Ariful, & Jun, 2020). Infectious diseases change social interaction patterns. During the Ebola outbreak, many studies pointed to changes in social customs playing a critical role in hindering disease spread. Similar behavioral responses played important roles in modifying disease spread in other pandemics, for example, wearing protective masks, decrease in unprotected sex or covering one's own cough and staying at home if sick. These responses to disease pervasiveness can, in turn, preempt disease spread by the infected to the susceptible individuals in the population. Individuals change their behavior during an epidemic in response to whether they and/or those they interact with are healthy or sick (Ceyhun, Jeff, & Joshua, 2017). One of the key questions of public health epidemiology, is how individual and community actions can help mitigate and manage the costs of an epidemic. Social distancing is an aspect of human behavior of particularly important because of its universality; individuals can reduce their contact rates with others by changing their behaviors, and reduced contact reduces the transmission of many diseases. Social distancing refers to the adoption of behaviors by individuals in a community that reduce those individuals' risk of becoming infected by limiting their contact with other individuals or reducing the transmission risk during each contact. Typically, this incurs some costs in terms of liberty, social capital, time, convenience, and money, so that people are only likely to adopt these measures when there is a specific incentive to do so. Social distancing practices can reduce the severity of an epidemic, but the benefits of social distancing depend on the extent of individual use. Individuals are sometimes reluctant to pay the costs inherent in social distancing, and this can limit its effectiveness as a control measure (Timothy, 2010). Visitors can play an important role in the transmission and spread of infectious diseases. They can serve as susceptible hosts and be infected while staying in one place and then act as mobile sources of case imports to other populations. Subsequently, some infectious diseases spread aggressively in major tourism destinations, and a large number of visitors can have surprising impacts on public health (Cui, Takeuchi, & Saito, 2006). Game theory attempts to analyze situations where individuals must make decisions in a group environment and where each individual's decision influences the pay-off received by the others in the group.

1.2 Scope of the Study

This research focused on the understanding of the concept of algorithmic game theory. This research would be limited to just game theory and to a single epidemic season to illustrate the stability of the epidemic models for the further evolutionary process.

1.3 Significance of Study

This research aims to show that game theory has a significantly wide application area ranging from social sciences to applied sciences and also to real life problems. Epidemiologist and healthcare practitioners can find severe areas of application of game theory in preventing and controlling the spread of infectious diseases.

II. LITERATURE REVIEW

While there are significant advances in information technology and infrastructure which offer new opportunities, cyberspace is still far from completely secured. While traditional techniques are effective in solving the particular problems they are designed for, they generally fail to respond well in a dynamically changing scenario. To this end, (Sajjan, Sankardas, & Dipankar, 2010) propose a holistic security approach - Imperfect information stochastic game. We find that game theory provides huge potential to place such an approach on a solid analytical setting.

How various methods of dynamic traffic routing can affect the performances of telecommunications network in which several telecommunications operators coexist. (Kostić-Ljubisavljević, Radonjić, Mladenović, & Aćimović-Raspopović, 2011) developed the software for Routing and Interconnection Simulation (RIS). Its main task is the traffic simulation in interconnected telecommunication network.

Designing and developing computer games can be a complex activity that may involve professionals from a variety of disciplines. (Mark, Mike, Denis, & Somasundaram, 2017) examined the use of game theory for supporting the design of gameplay within the different sections of a computer game and demonstrate its application in practice via adapted high-level decision trees for modeling the flow in gameplay and payoff matrices for modeling skill or challenge levels.

The traits (fixed and plastic) possessed by a plant, are commonly modelled as density-independent adaptations to its environment. Though, it may also represent density- or frequency-dependent adaptations to the strategies used by neighbours. (Gordon & Ray, 2013) reviewed game theoretical models of allocation; game theoretical models of enemy defence; and game theoretical models of trade with mutualistic partners.

Ecological study of various phenomena ranging from conflict behaviour to altruism to signaling and beyond. (Simon & Kevin, 2013) advocated for a more pluralistic methodology, which includes both static and dynamic game theoretic tools. Such an approach provides a more complete picture of the evolution of strategic behaviour.

To explain how these behavioral adaptations may affect the epidemiology of highly pathogenic avian influenza in domestic poultry and the outcome of the implemented control policies. (Alexis & Maciej, 2020) studied a symmetric population game where the players are broiler poultry farmers at risk of infection and where the between-farms disease transmission is both environmental and mediated by poultry trade.
Investigating the dynamics of disease conferring temporary or waning immunity with several forced-control policies. (Muntasir, Ariful, & Jun, 2020) proposed vaccination game theory.

An assumption in game theory is that players are opaque to one another, that is, if a player changes strategy, it does not affect the choice of other players' strategies. In many scenarios this assumption is unrealistic. (Joseph & Rafael, 2018) developed a framework for reasoning about games where the players may be translucent to one another; that is, a player may believe that their change strategies would require other players to also change their strategies
The rational choice theory is based on this idea that people rationally pursue goals for increasing their personal interests. (Gholamreza, Madjid, & Choonkil, 2019) presented a new concept of rational choice, Hyper-rational choice: in which the decision-maker thinks about profit or loss of other decision-makers in addition to his personal profit or loss and then will decide on an action that is desirable.

(Gregory & Bryan, 2019) presented a basic framework of psychological game theory (PGT) and linkages to the public choice literature. The distinction between PGT and other game-theoretic frameworks rests on the inclusion of beliefs about strategies directly within the players' objective functions. Thus, a natural extension of PGT includes the consideration of non-monetary drivers of behavior.

III. METHODOLOGY

In this chapter the methodology applied to solving the research problem is presented. Research methodology refers to the complete process that describes the type of research to be done, how the data used was collected and how it will be analysed, this information is presented in this chapter.

Table 3.1 : Proposed Methods

S/N	Author(s)	Proposed Methodology(ies)
1	(Timothy, 2010).	**Method:** A differential-game to identify how individuals would best use social distancing and related self-protective behaviors during an epidemic. **Description:** The epidemic is described by a simple, well-mixed ordinary differential equation model. Using the differential game to study potential value of social distancing as a mitigation measure by calculating the equilibrium behaviors under a variety of cost-functions. Numerical methods are used to calculate the total costs of an epidemic under equilibrium behaviors as a function of the

		time to mass vaccination, following epidemic identification. The key parameters in the analysis are the basic reproduction number and the baseline efficiency of social distancing.
2	(Ceyhun, Jeff, & Joshua, 2017)	**Method:** A stochastic network disease game model that captures the self-interests of individuals during the spread of a susceptible-infected-susceptible disease. The goal is to determine how behavior can change whether a disease will become endemic or not. **Description:** This explore the interrelationship among contact network structure, individual behavior, and disease spread dynamics. A stochastic network game where individuals respond to the current risk of disease spread, and their responses together with the current state of the disease and the contact network structure stochastically determine the next stage of the disease. In particular the game is played among the healthy and the sick with an SIS (Susceptible-Infected-Susceptible) infectious disease. In this scenario, the concern for disease contraction of a healthy individual increased with the number of sick contacts that are not taking any preemptive measures. Similarly, sick individuals had increased concerns for disease spread when there are more healthy contacts that do not take protective measures. This meant that the incentives for a healthy individual taking a measure decreased as more of individual's sick contacts took preemptive measures, for example, staying at home. Similarly, the incentive for preemptive measures decreased for sick individuals as the healthy got more cautious. The consequences of these incentives are not trivial in a disease contact network setting where an individual care about the behaviors of contacts who themselves care about their neighbors and so on. Hence, analysis focused on the impact of rational behavior on disease spread.
3	(Sofía, Virginie, & Romulus, 2017)	**Method:** An imperfect vaccine, which confers protection only to a fraction of vaccinees for a limited duration. The mathematical model combines a single-player game for the individual-level decision to get vaccinated, and a compartmental model for the epidemic dynamics. **Description:** A characterization for the effective vaccination coverage, as a function of the relative cost of prevention versus treatment; note that cost may involve monetary as well as nonmonetary aspects. Three behaviors are possible. First, the relative cost may be too high, so individuals do not get

		vaccinated. Second, the relative cost may be moderate, such that some individuals get vaccinated and voluntary vaccination alleviates the epidemic. In this case, the vaccination coverage grows steadily with decreasing relative cost of vaccination versus treatment. Third, where relative cost is sufficiently low so epidemics may be averted through the use of prevention, even for an imperfect vaccine.
4	(Shi, Chris, & Daihai, 2018).	**Method:** Incorporate an epidemic model into a game theoretical framework to investigate the effects of travel strategies on infection control. **Description:** Potential visitors must decide whether to travel to a destination that is at risk of infectious disease outbreaks. The research compared the individually optimal (Nash equilibrium) strategy to the group optimal (Pareto) strategy that maximizes the overall population utility. Economic epidemiological models often find that individual and group optimal strategies are very different. By contrast, perfect agreement between individual and group optimal strategies across a wide parameter regime. For more limited regimes where disagreement does occur, the disagreement is (i) generally very extreme; (ii) highly sensitive to small changes in infection transmissibility and visitor costs/benefits; and (iii) can manifest either in a higher travel volume for individual optimal than group optimal strategies, or vice versa.
5	(Muntasir, Ariful, & Jun, 2020)	**Method:** Vaccination game theory, considering pre-emptive vaccination and forced control policies, two major protective approaches against the repeated pandemics and severe epidemics of several infectious diseases. This study uses a mixed control strategy relying on quarantine and isolation policies to quantify the optimum requirement of vaccines for eradicating disease prevalence completely from human societies. **Description:** Relying on the basic concepts of the voluntary vaccination program, individuals are requested to decide at the beginning of every recurring season whether to be vaccinated again or not. This is because the protective efficacy of most vaccines lasts less than a year due to waning antibodies and year-to-year changes of the circulating virus. Hence, the evolutionary dynamics of this proposed model consists of two stages. The first stage includes a vaccination campaign that allows individuals to make a rational decision to be vaccinated or not before any individuals are exposed to the epidemic strains. Vaccination inflicts a certain cost to every individual who is

		vaccinated. This stage of vaccination comes with the cost price which includes the monetary cost of the vaccine itself and the cost of miscellaneous perceived risk factors. However, an unvaccinated individual undergoes a risky state of becoming infected anytime during an epidemic. The second stage occurs during the epidemic season when the epidemic strain enters the population and a number of randomly selected susceptible individuals are marked as initially infected persons. Hereafter, the epidemic behaviors can be analyzed by a non-linear deterministic SVEIJR model proposed for the transmission dynamics of an infectious disease with quarantine–isolation control policies.

IV. Results and Discussion of Findings

In this paper, we attempted a glimpse at the captivating field of game theory; as it is presently experiencing intense investigation by the community of game theorists as well as computer scientists and epidemiologist. Although some essential theoretical questions have been resolved, there are still a lot of challenges ahead of us. The aim of game theory is to provide a systematic approach to decision making. It is being applied to evaluate scenarios between individuals and health organizations with contradictory objectives, in a pandemic. And the main aim of applying game theory is to find out the best strategy to resolve the pandemic problems. The applications of game theory are more varied and are forcing us towards more and more collaborations across behavioral sciences, biology and computer science in particular. After reviewing the literatures on the reviewed methodologies, a table of their expected results and limitation are highlighted in the Table 4.1 below.

Table 4.1 : Expected Results and Limitations of the Reviewed Methodologies

S/N	Author(s)	Expected Results and Limitation(s)
1	(Timothy, 2010).	**Expected Result:** Social distancing is most beneficial to individuals for basic reproduction numbers (R0) around 2. In the absence of vaccination or other intervention measures, optimal social distancing never recovers more than 30% of the cost of infection. Also, shows how the window of opportunity for vaccine development lengthens as the efficiency of social distancing and detection improves. **Limitation:** The net savings from social distancing reaches a maximum around R0˜2, and never saves more than 30% of the cost of the epidemic per person. For larger R0's, social distancing is less beneficial.
2	(Ceyhun, Jeff, & Joshua, 2017)	**Expected Result:** Individuals strategically modify their behavior based on current disease conditions. These reactions influence disease spread. Also, there is a critical level of concern, that is,

		empathy, by the sick individuals above which disease is eradicated rapidly. Furthermore, the risk averse behavior by the healthy individuals cannot eradicate the disease without the preemptive measures of the sick individuals. Empathy is more effective than risk-aversion because when infectious individuals change behavior, they reduce all of their potential infections, whereas when healthy individuals change behavior, they reduce only a small portion of potential infections. **Limitation:** This imbalance in the role played by the response of the infected versus the susceptible individuals on disease eradication affords critical policy insights.
3	(Sofía, Virginie, & Romulus, 2017)	**Expected Results:** Voluntary vaccination may lead toward epidemic elimination if two conditions are met. First, the duration of vaccine-induced immunity should be sufficiently long. Second, the relative cost of prevention versus treatment must be sufficiently low. Disease elimination may occur when a high-performance vaccine is made available, at low cost, in an endemic setting where individuals witness disease-related morbidity and mortality, as well as the benefits of vaccination, as disease incidence declines. This yields a low relative cost of prevention versus treatment, resulting in a vaccination coverage high enough to avert the epidemic. However, the modeling results show that disease epidemic elimination is only temporary. Indeed, as vaccination coverage increases, leading to less epidemic adversity, individuals may also lose their initial motivation to vaccinate. Hence, with epidemic elimination, the perception of cost in the dilemma of prevention versus treatment may change and increase. In turn, this causes a decrease in vaccination coverage and reverses disease elimination. However, it is very important to note that, once the epidemic is averted (in region (a)), the dynamics toward the situation may be slowed down significantly, owing to continuous effort from the public health authority to maintain a low cost for vaccination. **Limitation:** Disease elimination is only temporary—as no equilibrium exists for the individual strategy in this third case—and, with increasing perceived cost of vaccination versus treatment, the situation may be reversed toward the epidemic edge, where the

		effective reproductive number is 1. Thus, maintaining relative cost sufficiently low will be the main challenge to maintain disease elimination.
4	(Shi, Chris, & Daihai, 2018).	**Expected Result:** The simulations show qualitative agreement with the 2003 severe acute respiratory syndrome (SARS) outbreak. The research concluded that a conflict between individual and group optimal visitor travel strategies during outbreaks may not generally be a problem, although extreme differences could emerge suddenly under certain changes in economic and epidemiological conditions. When a disagreement between the individual and group optimal strategies occurs, the discrepancy was very large and highly sensitive to small changes in disease transmissibility and visitor costs/benefits. **Limitation:** Travelling players may not always be informed about outbreak events in a timely manner.
5	(Muntasir, Ariful, & Jun, 2020)	**Expected Result:** The numerical simulations presented in this study emphasize the importance of applying a quarantine or isolation policy in preventing the spread of infection. Especially at times when the majority of people do not prefer vaccination due to its meager efficacy or higher cost, these control policies applied by the governing authority can somehow provide an ambience of relief amid them. Backed by the numerical simulation, it is obvious that adopting a quarantine–isolation policy can calm a difficult situation in a hopeless region too. The theoretical analysis also suggests that a joint policy should be implemented when the disease spreading rate is higher. The relative contributions from either pre-emptive vaccination or late control policies are equally important to keep the final epidemic size at a controllable state. This model can successfully address the importance of dual provisional safety in terms of public health issues which has never been investigated before using the framework of evolutionary game theory. Unlike some of the previous studies, this model does not encounter any intermediate protection measure *vis-a-vis* wearing a mask, gargling, drinking an energy drink, as a distinct strategy like being vaccinated or any other control policies. On another note, analysis can also be extended further by integrating other control methods such as source reduction, information spreading, free-vaccination,

		and adequate vaccine campaigns with different modes of action in rotation and combination. **Limitation: S**hifting from voluntarily adopted pre-emptive vaccination to a forcefully applied quarantine or isolation policy seems way too extreme in reality.

The various aforementioned game theory framework for infectious diseases can be further categorized into prevent or control, based on the application each framework favours the most. Prevent means it can be utilized in case of a pandemic, to administer vaccines to individual and treatment to infected individuals. While control means it can be utilized in case of a pandemic, to control the wide spread of the infection.

Table 4.2 : Categorization of the Reviewed Methodologies

Author(s) and Year	Game Theory	Prevent	Control
(Timothy, 2010)	A differential-game		Yes
(Ceyhun, Jeff, & Joshua, 2017)	A stochastic network disease game model		Yes
(Sofía, Virginie, & Romulus, 2017)	An imperfect vaccine	Yes	
(Shi, Chris, & Daihai, 2018)	A game theoretical framework (Nash Equilibrium and Pareto)		Yes
(Muntasir, Ariful, & Jun, 2020)	Vaccination game theory	Yes	Yes

From Table 4.2, it can be seen that the method proposed by (Muntasir, Ariful, & Jun, 2020) offer a better and more robust solution.

Game theory provides appropriate solution to a problem if its conditions are properly satisfied. These conditions, often called assumptions are:

- Assumes that decision-makers can adopt multiple strategies for solving a problem
- Assumes that there is an availability of pre-defined outcomes
- Assumes that the overall outcome for decision-makers would be zero at the end of the game
- Assumes that decision-makers are aware of the rules as well as outcomes of other decision-makers
- Assumes that decision-makers take a rational decision to increase their profit.

V. Summary, Conclusion and Recommendations

Game-theoretic models has been used to discuss the dilemma of prevention versus control. Demonstrating the circumstances under which non-cooperative, self-interested individuals arrive to alleviate, and potentially eliminate, an epidemic through the use of Game theory. Maintaining a low relative cost of prevention versus control will be the main challenge to maintain disease elimination unless incentives are considered.

Game theory is the study of conflict and cooperation amongst intelligent rational decision-makers. It is a prevailing analytical tool in understanding the phenomena that can be observed when decision makers interact. To stay up-to-date with the various realities of game theory applications, game theorists must arrangement and maintain a dialogue with the industry practitioners. Game theory may influence practice, but practice must influence the development of appropriate models if game theory is to be more than an exercise in a minor branch of pure sciences.

Furthermore, appropriate models cannot be built without an understanding of context and both the models and their formal analysis are required to bring the influence of game theory into the domain of public discourse and appreciation. It also allows researchers to analyze the performance of scenarios relative to the theoretical optimum. Game theoretic models has been successfully applied to a wide variety of disciplines including computer science, medicine, economics, sociology, psychology, philosophy. And, has helped improve our perceptions, allowing a rational reconstruction of different ideas, norms, values among decision-makers for significant philosophical expositions.

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