FORECASTING THE DECISION BASED ON RISK PERCEPTION USING BAYESIAN GAME THEORY APPROACH IN PREVENTING HAND, FOOT AND MOUTH DISEASE (HFMD) IN PULAU PINANG, MALAYSIA

SITI NURLEENA BINTI ABU MANSOR

UNIVERSITI SAINS MALAYSIA

2023

FORECASTING THE DECISION BASED ON RISK PERCEPTION USING BAYESIAN GAME THEORY APPROACH IN PREVENTING HAND, FOOT AND MOUTH DISEASE (HFMD) IN PULAU PINANG, MALAYSIA

by

SITI NURLEENA BINTI ABU MANSOR

Thesis submitted in fulfilment of the requirements
for the degree of
Doctor of Philosophy

July 2023

ACKNOWLEDGEMENT

First and foremost, I praise and thank God (Allah) for giving me the opportunity, knowledge, health, and blessings to complete this thesis. The completion of this thesis would not have been possible without the support and encouragement of several special people along the way. Hence, I would like to take this opportunity to show my gratitude to those who have supported me in a variety of ways.

I am grateful to my main supervisor, Associate Professor Dr. Farah Aini Abdullah, and my co-supervisor, Dr Majid Khan Majahar Ali, for giving me the opportunity to do research in a positive and stimulating environment, and above all, for showing me the way to conduct research. This thesis would not have been possible without their suggestions, advice, and support. I would also like to thank my former supervisor, Associate Professor Adam Baharum, it was a great privilege and honour to work and study under his supervision. I am extremely grateful for what he has offered me. I would like also to thank all the School of Mathematical staff at Universiti Sains Malaysia (USM) for all their administrative help through these years.

My warmest thanks to my family who has given me constant encouragement, support, and inspiration. I owed a great deal. To my late mother, Naemah Yaacob, thank you. You are gone, but your belief in me has made this journey possible. To my father, Abu Mansor Daud, for his never-ending support, encouragement, and generosity, as well as for imparting his wisdom upon me and for teaching me patience. A special thank goes to my beloved husband, Muhamad Sallehuddin Ahmad for his love, great patience, and support in every single moment of my life during the past 11 years. He has devoted his time and effort towards helping me achieve success. Also, special thanks go to my wonderful children, Owais Muhseen and Owais Muneer for their support and being patient with me while I have been busy completing my doctoral

studies the last couple of years. I thank you all for always making me smile and for understanding my absences on those weekends and holidays when I was working on my research instead of playing games with you. I hope that one day you will understand why I spent so much time in front of my computer. Also, I thank all my brothers and sisters for their moral support.

Finally, I would like to thank my colleagues at USM for the great time we spent together and for their help and support. Not forgetting, my colleagues at Universiti Teknologi MARA, Cawangan Pulau Pinang, I would like to extend my sincere gratitude to everyone who has directly or indirectly supported me to complete my research work. I would like to express my gratitude to all the wonderful people who have contributed to this thesis and gave me the chance to accomplish a dream.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF APPENDICES

PERAMAL KEPUTUSAN BERDASARKAN PERSEPSI RISIKO MENGGUNAKAN PENDEKATAN TEORI PERMAINAN BAYESIAN DALAM MENCEGAH PENYAKIT TANGAN, KAKI DAN MULUT (HFMD) DI PULAU PINANG, MALAYSIA

ABSTRAK

Penyakit tangan, kaki, dan mulut (HFMD) adalah antara wabak penyakit yang sering berlaku dan sehingga kini, masih belum ada vaksin yang berkesan. Berpunca daripada enterovirus yang biasanya dikenali sebagai jenis virus Coxsackie A16 dan Enterovirus 71, penyakit ini selalu berlaku di kalangan bayi dan kanak-kanak di bawah umur lima tahun. Dalam penyelidikan ini, model wabak HFMD di Seberang Perai Tengah, Pulau Pinang telah dikaji. Bilangan kes mingguan digunakan untuk membandingkan model wabak HFMD dengan, dan tanpa sebaran virus dalam persekitaran dan mempertimbangkan nilai sebaran mereka. Tambahan pula, tingkah laku manusia menjadi faktor utama dalam sistem penularan penyakit HFMD. Keberkesanan intervensi sebahagian besarnya bergantung kepada tingkah laku penduduk. Persepsi risiko membentuk tingkah laku manusia dalam pelbagai cara, terutamanya dalam membuat keputusan. Di sini, faktor-faktor yang menentukan persepsi risiko ibu bapa terhadap penyakit HFMD dan cara untuk mengukur tahap risiko mereka telak diteroka. Faktor-faktor seperti pengetahuan tentang HFMD, kepercayaan kesihatan, tingkah laku pencegahan dan pengalaman disatukan, dan dianalisa untuk membangunkan rangka kerja hubungan dengan persepsi risiko. Apabila membuat keputusan yang berkaitan dengan tingkah laku kesihatan, keputusan seseorang tidak memberi pengaruh terhadap keputusan orang lain. Selain itu, jika hanya minoriti yang mengubah tingkah laku mereka, tidak akan ada perbezaan yang bererti dalam menghentikan penyakit ini, yang mana kesemua faktor seperti pengetahuan, pengalaman dan persepsi risiko merupakan jenis (*types*)

kelakuan berbeza . Maka, teori permainan Bayesian merupakan teknik yang lebih tepat untuk meramalkan pemilihan strategi setiap inidividu. Hasil dapatan menunjukkan ramalan keputusan ibu bapa dan persepsi risiko adalah berdasarkan keutamaan mereka (*types*). Ibu bapa yang tiada pengalaman dalam mengendalikan HFMD dan mempunyai tahap kepercayaan kesihatan yang rendah membawa kepada kebarangkalian tinggi untuk membuat keputusan menghantar anak mereka yang dijangkiti ke tadika. Kesimpulannya, keputusan analisa dari penyelidikan ini dapat digunakan untuk meramal tingkah laku ibu bapa apabila berlaku penularan wabak, dan intervensi yang tepat dapat diuruskan secara berkesan menggunakan teori permainan Bayesian. Akhirnya, dicadangkan kajian masa hadapan boleh meneroka rangka kerja model yang membenarkan perhubungan antara populasi, persekitaran dan masa yang sesuai untuk pelbagai intervensi. Faktor lain yang mempengaruhi pemilihan struktur model termasuk, masa dan sumber yang tersedia, serta ketersediaan dan kebolehgunaan model yang dibina sebelum ini.

FORECASTING THE DECISION BASED ON RISK PERCEPTION USING BAYESIAN GAME THEORY APPROACH IN PREVENTING HAND, FOOT, AND MOUTH DISEASE (HFMD) IN PULAU PINANG, MALAYSIA

ABSTRACT

Hand, foot, and mouth disease (HFMD) is amongst common diseases which often occurs in outbreaks and up to now, there is no effective vaccine yet to be found. Known to be caused by enterovirus usually typed Coxsackie virus A16 and Enterovirus 71, this disease is common among infants and children below the age of five. In this research, the HFMD epidemic models in Seberang Perai Tengah, Pulau Pinang are examined. Number of cases in epidemic week are used to compare HFMD epidemic model with and without virus shedding in the environment and contemplate their reproduction numbers. Furthermore, human behaviour has become the main factor in HFMD disease transmission systems. The effectiveness of interventions is largely dependent on the behaviour of the population. Risk perception shapes human behaviours in many ways, especially in decision making. Here, the factors that determine parents' risk perception on HFMD disease and how they quantify their level of risk are explored. Factors such as knowledge of HFMD, health beliefs, preventive behaviour, and experienced with HFMD are put together and analysed to develop a framework to show the relationship with risk perception. Moreover, when making decisions related to health behaviours, one's decisions do not influence the decisions of others. In addition, if only a minority changes their behaviour, there will not be a significant difference in stopping this disease, whereas all factors such as knowledge, experience and risk perception are the different types of behaviour. Therefore, Bayesian game theory is a more accurate technique for predicting each individual's strategy selection. Results show the forecast of parent's decision and risk perception based on their preference (types). Parents with no experience in handling HFMD and

have low level of health belief lead to high probability of taking chances to send their infected child to kindergarten. In conclusion, the results from this research can be used to forecast the behaviour of parents when there is an outbreak, and the right intervention can be managed effectively using Bayesian game theory. Finally, it is suggested that future studies could explore a model framework that allows for the relationship between population, environment, and time appropriate for various interventions. Other factors that influence the choice of model structure include, available time and resources, as well as the availability and usability of previously constructed models.

CHAPTER 1

INTRODUCTION

1.1 General Background

Since the start of the humankind, infectious diseases have moulded the histories and they remain with us until today. Infectious diseases are illness caused by the spread of microorganisms to human from other humans, animals, or the environment. Diseases such as measles, HIV/AIDS, tuberculosis, Ebola, dengue, and recently COVID-19, are part of diseases that still taunting human health that led to the high rate of mortality across the globe (Walker et al., 2020). As a major public health challenge, these prolonged infectious diseases assured significant adverse impact in the development of society and economics.

Concurrently, the world has also developed and improved the global health system against infectious disease threats with tremendous hard works. The World Health Organisation (WHO) plays an important role in the attainment of public health (www.who.int). WHO helps enhanced the organisations, modalities, resources, and accountability in order to operate across different levels, from local to global. These progressions have greatly aided in the protection and promotion of human health through high technology pharmaceutical research and development of vaccination for eradication of diseases.

However, the world continues to be confronted by longstanding, emerging and re-emerging infectious disease threats. Healthcare between countries, for instance developed countries (United States, United Kingdom, Germany) and underdeveloped countries (Nigeria, Somalia, Central Africa), show immense differences in the infrastructures, medicines, providers, and education. Most residents in those low-

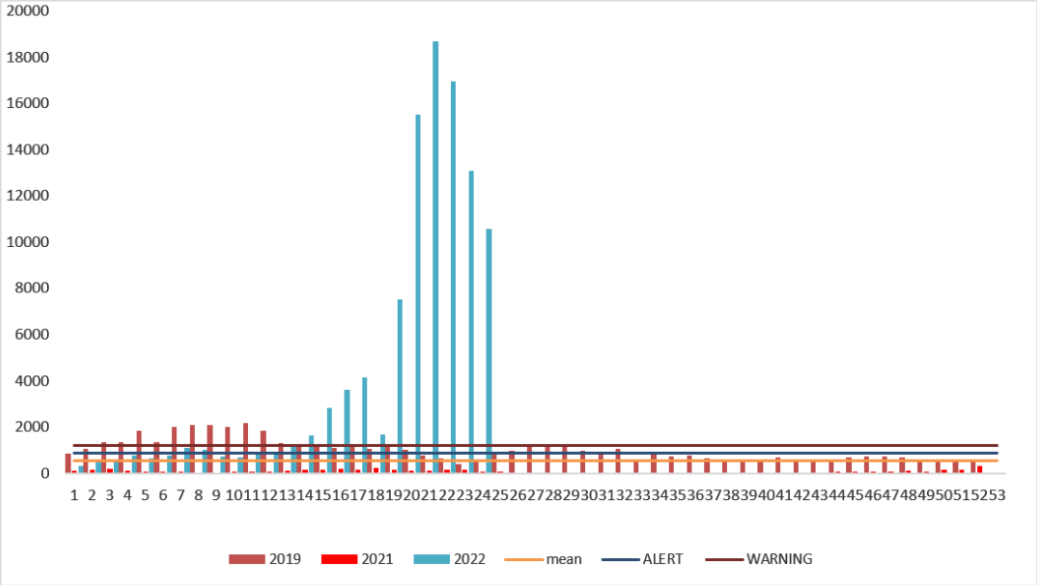
income countries are suppressed by poverty which led them to not seek care or treatment, making halting infectious diseases difficult.

Hand, foot, and mouth disease (HFMD) is one of the common transmissible diseases which often occurs in outbreaks and up to now, there is no effective vaccine yet to be found (Bello and Roshorm, 2022). Known to be caused by enterovirus usually typed Coxsackie virus A16 and Enterovirus 71, this disease is common among infants and children below the age of five (Pheng et al., 2022). Children with low immunity to most common viruses are prone to get HFMD that related with symptoms like fever, ulcers in mouth and throat, loss appetite, sore throat, and rashes on hands, foot, and nappy line. Even with usual signs that are thought not to be harmful, there is always a possibility of complication which can lead to death.

HFMD can be transmitted through the respiratory through inhaling infectious droplets by close contacts with infectious crowds, touching virus-carrying hands, towels, handkerchiefs, toys, utensils, bedding, and underclothes, and via the gastrointestinal tract through contaminated water and food. Has been noted that the pathogen of EV71 can survive for a long period outside the host in suitable conditions (Head, 2022) and even 75% alcohol cannot eliminate the virus.

Malaysia has experienced five outbreaks of HFMD since its first recorded emergence in the Sarawak outbreak in 1997, witnessing 31 deaths of children aged five months to six years with 2628 reported cases. Since then, the total number of cases keep building up occasionally. Recently in 2022, recorded a total of 95,924 reported cases up until 11 June, higher than year 2021 (2,654). The highest cases were in Selangor (26,799 cases) followed by WP Kuala Lumpur (10,739 cases), and Perak (9,744 cases) with a huge different compared to last year (Figure 1.1). To date,

there are three cases of HFMD admitted to the intensive care unit (ICU), one of the cases was already allowed to return home.



Source: www.kpkesihatan.com

Figure 1.1: Trend HFMD cases in Malaysia (2019 – Epidemic week 22,2022)

It is upsetting to know that more than 90% of the cases every year are children below ten years old. Table 1.1 shows the division of cases by age groups with the highest number is in the age group of 0-4 years old. Obviously, at this stage of age the children are likely to transmit the disease because of their misconceived on the precautionary measures (Mohamad et al., 2021). It is common in children because of frequent diaper changes or toilet training (touches an infected child's feces), coughs or sneezes (contact with droplets containing virus), hugging or kissing (touching infected person), and they often put their hands in their mouths after touching toys (touching contaminated objects and surfaces). The majority of outbreaks occurred in nurseries, kindergartens, and pre-schools, with 1,059 outbreaks (61%) followed by private homes with 605 outbreaks (35%) and childcare centres with 56 outbreaks (3%) (https://kpkesihatan.com/2022/06/07/kenyataan-akhbar-kpk-7-jun-2022).

Table 1.1: HFMD cases by age groups in Malaysia (2014-2017)

Age groups	2017	2016	2015	2014
0 – 4	23,706	37,253	18,095	24,497
5 – 9	4,205	7,409	3,265	5,250
≥ 10	1,448 (4.93%)	2,346 (4.99%)	1,227 (5.43%)	1,575 (5.03%)
Total	29,359	47,008	22,587	31,322

**Source: https://www.data.gov.my*

It conveys the importance of parents' perceived risk in order to follow the infection control policies given by the health authority (Liu et al., 2021). Among the infection control listed by the Ministry of Health, Malaysia, are good personal hygiene and disinfected environments, isolation of the infected person at least ten days, and closure of kindergarten/nurseries if there occur two or more cases in the premise.

1.2 Problem Statement

Infected children who are not been isolated or quarantined can transmit the disease by contaminating the area or items they touched (Jia et al., 2021; Chadsuthi and Wichapeng, 2018). Children are known to be physically active will easily spread the disease and increase the number of infections. It is important to trace the infected child movement as virus shedding can contaminate the area; this implies the need to sterile the infectious area (Gadsden-Hevia, 2021). Besides that, it is known that the incubation period of HFMD is generally two to seven days. During these period, infected children are restricted to attend their kindergarten or nursery to prevent the contamination of the environment and transmission of HFMD to other children (Thammasonthijarern et al., 2021). Consequently, the caregivers or either one of the parents need to be absent from work in order to carter for the sick children. Some parents who cannot afford to leave their job, take the risk, and still send their children to the kindergarten. At the same time, some other parents may see this disease as

not life threatening for them, but little they realise that it is a huge risk for the children. Less we know how they evaluated their risk perception of HFMD and how it influenced their protective behaviours.

Undoubtedly, human behaviour has become the main factor in disease transmission systems (Buckee et al., 2021). The effectiveness of interventions (clinical or non-clinical) is largely dependent on the behaviour of the population (Rajamoorthy et al., 2022). Public health authorities need to know how people perceive risks, how they perceive the effectiveness and acceptance of interventions and whether they will trust and be willing and able to use information from public health personnel and other reliable sources. Seems that risk perception does play an important role in behaviour changes (Sun et al., 2021). Brug et al. (2009) indicated three key factors that influenced people to change their behaviour. First, individual need to have awareness on the risks upon them. Second, they must believe the intervention provided, and lastly, communications about the disease should carefully managed to avoid panic among public.

The factors that determine parents' or caregivers' risk perception on HFMD disease need to be explored and how they quantify their own level of risk versus their children. Factors such as knowledge of HFMD, health beliefs, preventive behaviour, information related to HFMD, and responsibility towards risk of HFMD should be analysed to have clear understanding of their risk perception. Furthermore, human behaviour has become the main factor in disease transmission systems. The effectiveness of interventions is largely dependent on the behaviour of the population as risk perception shapes human behaviours in many ways, especially in parents' decision making.

1.3 Research Questions

i) How is the nature of the HFMD model when virus shedding is included in the model, considering it happen in a close area such as kindergarten or nurseries?

ii) What are the factors that variate risk perception among parents during HFMD outbreak?

iii) How is Bayesian game theory used in forecasting the risk perception among parents to prevent HFMD transmission in kindergarten or nurseries?

1.4 Objectives

The objectives of this thesis are as follows:

General: The objective of this study is to develop and forecast the behaviour based on the risk perception of parents using Bayesian game theory approach in preventing HFMD in Seberang Perai Tengah, Pulau Pinang.

Specific:

1. To identify the parameters value of HFMD model in Malaysia with quarantine as control measure, and indirect transmission through virus shedding into the environment from infected individual.
2. To investigate the behavioural changes driven by risk perception among parents, which could lead to HFMD transmission among children in contaminated environment.
3. To develop Bayesian games (*types*) based on the risk perception towards behaviour of parents in making decision for their children.

1.5 The Scope of Study

This study required primary and secondary data. The *primary data* is collected using survey by constructed questionnaire. The questionnaire is distributed using online survey among respondents in Seberang Perai Tengah, Pulau Pinang. The population involved parents or caregivers whose children is below the age seven and registered in nurseries (Aged 0-4 years old) or kindergartens/preschools (Aged 5-6 years old). This survey is a stratified random sampling that involves the division of a population into smaller groups. The study has chosen Seberang Perai Tengah (SPT), Pulau Pinang to distribute the survey. SPT district is divided into 21 mukims (strata) and also consist of four towns which are Bukit Mertajam, Perai, Bandar Perda and Seberang Jaya. Based on data from Department of Social Welfare Malaysia, there are 39 registered nurseries and kindergartens in SPT altogether. The other nurseries or kindergartens are not within the scope of this research. The *secondary data* is obtained from Ministry of Health (MOH), Malaysia (https://www.data.gov.my/data/en_US/dataset/penyakit-hfmd). The study population consisted of patients contracted with HFMD which recorded by MOH for 52 epidemics weeks in year 2014 until year 2017, all over Malaysia.

1.6 Significance of the Research

This research would be beneficial to three groups: health providers/the policy makers, nursery/kindergarten owners and parents/caregivers. First, the health providers/the policy makers could quantify issues on contaminated area of HFMD in SPT, Pulau Pinang focusing on nursery and kindergarten. The reproduction number obtained from the epidemic models constructed in this study may perhaps contribute to decisions, plans, and action to achieve specific healthcare goals to halt HFMD. Second, the nursery and kindergarten owners can have information regardless risk

perception among parents/caregivers. Since there is still no effective vaccine for HFMD and depend on the precaution measure such as quarantine or social distancing, this study investigated the behavioural changes driven by risk perception among parents/caregivers when their children are infected with HFMD. Lastly, the parents/caregivers received information based on their decision of behaviour. Explored evolutionary game in risk perception in this study provided multiple possibilities regarding one's decision in choosing to quarantine their infected children.

1.7 Organisation of Thesis

This thesis is organised in the following manner:

Chapter 1. **Introduction.** Introduction and the background to the research was explained in the beginning of this chapter, followed by the problem statement, the research objectives, the research questions, the scope of study, and the significance of research.

Chapter 2. **Literature Review.** In this chapter a brief historical background of mathematical models in epidemiology is given. A review of hand, foot, and mouth disease (HFMD) and mathematical models that represent the transmission dynamics of HFMD has also been included. Also, literature on the influenced of contaminated environment on HFMD transmission are conferred. Furthermore, studies on behavioural epidemiology in infectious diseases are reviewed and behaviour of parents towards handling their sick children are discussed based on risk perception and decision making. Moreover, Bayesian game theory is used as an altenative method in forecasting behaviour in decision making.

Chapter 3. **Methodology.** A brief and clear explanation on how this study is conducted in order to achieve the objectives listed in Chapter 1 is provided in this

chapter. Basic HFMD epidemic model of SIR is displayed, and extended model with quarantine and contaminated environment are presented. Parameter values are estimated to obtain the basic reproduction number. Variation of the reproduction number with related rates are plotted to discuss on the progression. Structural equation model (SEM) is used to develop a framework on risk perception that shapes parents' behaviour. Later, Bayesian game approach is used to map the strategies and forecast the decisions.

Chapter 4. **Results and Discussion.** In this chapter, findings are presented and the interpretation on the findings are provided. Estimated parameters and reproduction numbers are displayed. Variation of the reproduction number with transmission rate, quarantine rates, and indirect transmission rate are plotted. Then, we proposed a framework containing the constructs of health belief, preventive behaviour, knowledge, experience, and risk perception using structural equation modelling (SEM). Next, we presented the distribution over the set of type profiles such that player's *beliefs* given their *types*, and the values are the conditional probability distribution computed using Bayes' formula. Later, discussion is made regarding the findings.

Chapter 5. **Conclusions.** This chapter presents the conclusions and suggestions for future research in related to HFMD studies. Limitations of this study are also provided in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter deals with the review of related literature from the initial to the latest works in three interrelated area of study. This review begins with the mathematical epidemiology in general and HFMD model in specific, subsequently to HFMD model in contaminated environment. Then, works of behavioural in epidemiology directed to parents' behaviour towards HFMD among their children, and followed by developed frameworks on health belief and preventive behaviour with risk perception. Afterwards, the works of game theory in forecasting behaviour, accentuated on Bayesian game.

2.2 Mathematical Models in Epidemiology

Mathematical model has become important tools for investigating and understanding transmission dynamics and disease control. Public health physicians were responsible for a lot of the early advances in the mathematical modelling of communicable diseases. In 1760, Daniel Bernoulli, a member of a prominent family of mathematicians, who had been trained as a physician, provided support for the practise of smallpox vaccination inoculation. En'ko (1889) is credited with the first contributions to modern mathematical epidemiology, and other public health specialists like Hamer (1906), Ross (1911), McKendrick, and Kermack (1927, 1932 and 1933) laid the groundwork for the entire compartmental model-based approach to epidemiology.

More epidemiologic information should be included to create realistic epidemic models, such as stages of infection, age structure, social groups, vertical transmission, spatial spread, latent period, demographic, vaccination, quarantine, passive immunity, and immunisation. Most epidemic models have been formulated according to their specific nature of diseases, like, HFMD, influenza, malaria, measles, chickenpox, smallpox, HIV, and syphilis.

For instance, in order to comprehend the measles epidemic consistence reappearances, Hamer (1906) created a straightforward discrete-time mathematical model and looked at its characteristics. He proposed the mass action concept, which states that the rate of contact between susceptible and infectious populations determines how an epidemic will develop. Soper (1929) then studied expansively on damped oscillations in measles modelling. In 1957, Bartlett introduced two important characteristics, the mean period between epidemic and the community size, later extended to critical community size (Bartlett, 1960). Anderson and May (1982) studied the impact of vaccination on measles epidemics and assessed the vaccination threshold needed to remove the disease from the population. Schenzle (1984) included age-structured model to investigate on the pre-and post-vaccination for measles transmission. Bolker (1993) suggested realistic age-structured (RAS) model and partially structured measles model. More studies have arisen on the vaccine strategy on preventing measles (Gay et al., 1995; Bolker and Grenfell, 1996; Mossong et al., 1999).

The work of Ross (1911) on the dynamics of malaria transmission between mosquitoes and humans was demonstrated brilliantly, which qualified him to receive the second Nobel Prize in Medicine. He presented a straightforward compartmental model that includes both humans and mosquitoes. He demonstrated that malaria might be wiped out by bringing the mosquito population down to a critical threshold. The basic reproduction number, which has since become a crucial concept in

mathematical epidemiology, was first introduced in this context. Kermack and McKendrick expanded on the ideas created by Hamer and Ross in their well-known three series of study in 1927, 1932 and 1933. Reasons of epidemic ended before all susceptible were infected was explained comprehensively. They distinguished that the introduction of a few infectious individuals into a community of susceptible would not result in an epidemic breakout except the density or number of susceptible was over a certain critical value.

Recently, mathematical modeling is used to predict the development trend of COVID-19 that has been spreading worldwide. Many studies focused on epidemic prediction models of COVID-19 and the public health intervention strategies in halting the disease (Xiang et al., 2021; Lü et al., 2021; Zhao and Chen, 2020). Demongeot et al. (2020) introduced Susceptible-Infected (SI) epidemic model to COVID-19 data in China for early stage of the epidemic. They used the model to derive the parameters identification. In addition, Rihan et al. (2020) used stochastic epidemic Susceptible-Infected-Recovered-Cross-immunity (SIRC) model to analyse the model and prove the existence and uniqueness of positive global solution. Also, Korolev (2021) proposed the model to Susceptible-Exposed-Infected-Recovered-Dead (SEIRD) for COVID-19 and discussed on methods to estimate reproduction number.

2.2.1 Hand, Foot, and Mouth Disease (HFMD) Models

Hand, foot, and mouth disease (HFMD) is a common infectious disease of early childhood caused by a group of viruses known as enteroviruses, such as Coxsackieviruses with EV-A and EV-B serotypes (Bracho et al., 2011; Xing et al., 2014). The most common HFMD viruses are coxsackievirus A16 (COX A16) and enterovirus 71 (EV71), both of which can cause serious complications and potentially life-threatening illnesses (Qi et al., 2011). Fever, sore throat, ulcers on the hands, feet,

and mouth are symptoms of the illness, which can also lead to myocarditis, pulmonary edoema, aseptic meningoencephalitis, and other consequences. Direct contact with nasal discharge, saliva, infected stool, and blister fluid can all spread HFMD. Children below ten years old are predominantly affected with HFMD, but it can also affect adults. Adults, despite most of them are exposed to the virus, are immune to the sickness because of the antibodies in their bodies (Li et al., 2014). The first week of the sickness is a prime time for the transmission to happen. Even if the patient is symptom-free, the virus may still be transmitted. Adults are more resistant to the virus' virulence than children are, and it can remain in the faeces for up to 6 to 8 weeks. After infection, one develops immunity to the particular viral serotype that triggered the sickness. The sickness might spread again if the patient contracts a different viral serotype without showing any symptoms. Although there is currently no known medication or cure for this illness, World Health Organisation (WHO) has advised those who are infected to take symptomatic medication to reduce the pain around their ulcers (www.wpro.who.int, accessed 15 Dec 2021).

Finding ways to stop the transmission of HFMD has received a lot of interest due to its widespread nature and the morbidity and mortality it causes (Liu, 2011). The foundation of HFMD control methods is implementing the necessary preventative measures in the absence of an efficient anti-HFMD therapeutic therapy and vaccine. These precautions include quarantine techniques and individual protections against contact with infected people. Therefore, it is critical to comprehend how HFMD spreads among vulnerable communities in order to help policymakers stop the disease's spread and lessen its negative effects. Statistical models have been used in the literature to comprehend the spatiotemporal transmission of HFMD and determine the connection between HFMD occurrence and climate. In the literature, mathematical models have been developed to quantify the spread of HFMD.

However, review of the published literature on mathematical modelling HFMD yielded very few results.

Started in 2003, Urashima et al. constructed a nonlinear mathematical model of HFMD related to climate conditions in Tokyo. They concluded that warmer climate led to higher cases of HFMD. Later in Taiwan, Wang and Sung (2004) studied on the prevalence of EV71 and traditional seasonal factor on the transformation function in simulations for Susceptible-Infected-Recovered (SIR) models of severe HFMD cases from 1999 to 2003. Details in deterministic SIR model is presented by Tiing and Labadin (2008) to predict the number of the infected and the duration of an outbreak in Sarawak, Malaysia. Their findings showed that the disease transmission could be halted by controlling the susceptible individuals.

Later the model is extended to reflect changes in environment, Halder and Roy (2010) proposed a Susceptible-Exposed-Infected-Recovered (SEIR) model of HFMD, where exposed compartment represents the number of asymptomatic infectious individuals in the population. Their results showed that HFMD transmission depended on the number of actively infected people in the population and the incidence transmission rate. Phutthichayanon and Naowarat (2015) proposed the effectiveness of hand washing campaign as a control strategy in the Susceptible-Exposed-Infected-Infected(severed)-Recovered ($SEII_AR$) model. They added additional compartment of the severe infected individuals (I_A) in their SEIR model. Despite control measure, Wu (2017) showed the importance of the basic reproduction number using SEIR model in Singapore of years 2015 and 2016. Pongsumpun and Wongvanich (2018) formulated the HFMD transmission using two SEIR models of two subclasses. They studied the models based on age structural group of children under the age of ten, and group of children over the age of ten. Zhan et al. (2019) integrated the SEIR model and Kalman filter method for real-time forecasting of HFMD using outbreak data in Beijing, China. Their model had succeeded to predict the peak week

of the outbreak. Later, Lamwong et al. (2021) extended the study by Pongsumpun and Wongvanich (2018) and conducted the global stability analysis for HFMD age structured population. Study by Verma et al. (2021) extended the model to Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) to comprehend the reinfections and introduced periodic seasonality in the model. In current study, in spite of solving the model using the ordinary differential equation, Majee et al. (2022) presented a fractional-order SEIR model with memory that considered treatment as the control parameter.

Quarantine measure is proposed in the HFMD model as one of the preventive measures in HFMD transmission. Liu (2011) constructed a periodic Susceptible-Exposed-Infected-Quarantine-Recovered (SEIQR) model to simulate the dynamics of HFMD transmission and showed that quarantine has a positive impact on controlling the spread of HFMD. Ma et al. (2013) extended the SEIQR model to Susceptible-Exposed-Infected-Infected(Asymptomatic)-Quarantine-Recovered ($SEII_eR$) model and considered a compartment of asymptomatic infectious individuals (I_e) using data of Shandong Province in China. Yang et al. (2013) also studied on SEIQR model to determine the optimal control by increasing the social distancing measures, decreasing quarantine rate and the improvement of medical environment. In 2014, study by Zhu et al. established a Susceptible-Exposed-Infected-Quarantine-Recovered-Susceptible (SEIQRS) model with periodic transmission rate in the spread of seasonal HFMD in Wenzhou. They emphasised on the control measure of increased the quarantine rate or decreased the treatment cycle. Li et al. (2014) also presented the parameter values in SEIQRS model using data of China from March 2009 to December 2012. Phonchan and Naowarat (2019) proposed a SEIQR model to study the dynamics of HFMD with effects of limited public health resources. When there are not enough doctors, nurses, hospital beds, and isolation areas in some hospitals, they suggested that the recovery rate was low.

Vaccination is also considered as one of the control measures, however, it is known that only EV71 vaccine existed and only been given in mainland China (Li et al., 2014; Wu et al., 2016). Pulse vaccination is also considered as a control measure, this led to a study by Samantha (2014). She analysed the SEIQR model with pulse vaccination and she concluded that large pulse vaccination rate will lead to eradication of HFMD. Tan and Cao (2018) constructed a Susceptible-Exposed-Infected(EV71)-Infected(CVA16)-Vaccinated-Recovered (SEIIVT) model aimed to gain insight of HFMD transmission in vaccinated population. Shi et al. (2020) investigated HFMD model with the effect of EV71 vaccination in China from January 2008 to June 2019. They divided the individuals to the vaccinated Vaccinated-Exposed-Infected-Infected (Asymptomatic)-Vaccinated-Recovered ($VEII_eR$) and unvaccinated Susceptible-Exposed-Infected-Infected(Asymptomatic)-Vaccinated-Recovered ($SEII_eR$) groups. Their finding showed that vaccination alone cannot eliminate the disease, hence, the efficient control is by reducing the contact rate and improve medical conditions. In 2021, Moneim and Mosa extended the SEIQRS model with seasonal contact rate and periodic vaccination strategy. Furthermore, Liu et al., (2021) suggested that bivalent vaccines could be the effective strategy to reduce HFMD incidence compared to monovalent vaccine.

2.2.2 Contaminated Environment Influenced in HFMD Transmission

Children are more susceptible to HFMD infection than adults because they are prone to have appropriate antibodies and self-protection knowledge. Infected children that are not being quarantine could release the virus and spread the disease when susceptible individual touches the free-living pathogens in the environment. It should be noted that the EV71 pathogen can persist outside the host for an extended amount

of time under suitable settings (Han et al., 2010). Hence, contaminated environments may play vital roles in HFMD transmission.

Wang and Xiao (2016) considered indirect transmission coming from contaminated environment to establish a Susceptible-Exposed-Infected-Infected (Asymptomatic)-Recovered-Contaminated Environment ($SEII_eRW$) model in China. They concluded that HFMD can easily transmitted through direct contact with infected person or indirect contact with contaminated objects and suggested the frequent cleaning and sanitisation of the environment. Later, Wang et al. (2016) extended the model with periodic transmission and vaccination rates in contaminated environment. Supporting study by Lu et al. (2016) discovered high rates of enteroviruses in two paediatric hospitals in Guangdong Province in July 2015, particularly the waiting room. This indicated the failure of disinfectant of contaminated environment. While Li et al. (2016) confirmed the existence of enterovirus in public facilities especially from playgrounds in Guangzhou.

Motivated by that, Shi et al. (2018) extended SEIQR and $SEII_eRW$ model to Susceptible-Vaccinated-Exposed-Infected-Infected(Asymptomatic)-Quarantine-Recovered-Contaminated Environment (SVEIIeQRW) model. They analysed the effect of vaccination, cleaning of contaminated environment and quarantine simultaneously using reported HFMD data in China from 2015 to 2017. Their findings indicated that increasing vaccination, quarantine and environmental health rates could reduce the incidence. Chadsuthi and Wichapeng (2018) also studied on the indirect transmission via-living pathogen from the environment. SEIIeHRW model is used to investigate the effect of contaminated environment and asymptomatic individual in Bangkok, Thailand. In Malaysia, study by Chan et al. (2017) added the incubation and post-infection virus shedding into the Susceptible-Exposed-Infected-Clinically Recovered (virus shedding)-Recovered (SEIPR) model. They used the model on prediction of Sarawak's HFMD outbreak in 2006. In 2019, Shi et al.

combined the effects of vaccination, contaminated environments and quarantine in a model of HFMD in China. Their study shows that increasing the rate of virus clearance, the vaccinated rate of infants and young children, and the quarantined rate of infectious individuals can effectively control the spread of HFMD in mainland China. Meanwhile, Wang et al. (2019) studied the effects of contaminated environments on seasonal HFMD infections in China and concluded that vaccination at a suitable time and regular cleaning could control HFMD infections. Furthermore, Kua and Pang (2020) studied on the potential of risk factors and hygiene practices in HFMD transmission. Recently, Li et al. (2023) proposed a new game-theoretic model considering voluntary vaccination against imperfection and the effects of indirect transmission from exposure to contaminants. To the best of our knowledge, there are not many studies have been done on mathematical modelling on HFMD with the effect of contaminated environment in Malaysia.

2.3 Behavioural Epidemiology in Infectious Diseases

Human behaviour plays a significant role in the spread of infectious illnesses and knowing how behaviour affects disease spread might help improve control efforts. One of the most central aspects of human infection dynamics is the heterogeneity in behavioural deviation of human themselves. In recent years, a number of studies in human mobility patterns listed in the literatures. Funk et al. (2009) suggested that the interplay of social network layout with illness features causes a shift in behaviour in individuals, and their findings show how this can loop back to influence disease dynamics. Later, Funk et al. (2010) investigated the effect of awareness on halting the disease using a simple model. They considered a wide range of possible replies to the situation of an endemic condition, of which individuals of the population may be aware or oblivious. Belik et al. (2011) developed a model for spatial epidemics on

individual mobility networks between home and destination locations. Dalziel et al. (2013) also showed that increased in human mobility patterns significantly increased the risk size of epidemics. Recently, Li et al. (2022) characterised human mobility patterns for Malaria in Myanmar. Sociodemographic structure also contributes to the infectious diseases spread. Fumanelli et al. (2012) structured social contact patterns with reproduction number and attack rate for 26 European countries. Tola et al. (2017) determined the effect of sociodemographic characteristics on tuberculosis patients using structural equation modelling. Currently, López-Gay et al. (2022) investigated the relationship between COVID-19 occurrence and sociodemographic factors in Barcelona.

According to the Health Belief Model (HBM), people would engage in preventive health behaviour when they perceive themselves to be endangered by pandemic events (perceived susceptibility) or believe that the disease will have major consequences for their health (perceived severity). HBM is developed by Rosenstock (1966) to predict behaviour response to treatment and consists of four constructs: perceived susceptibility, perceived severity, perceived benefits, and perceived barriers. Then in 2004, Tang et al. modified the HBM to five constructs with additional construct of cues to action. The model's initial purpose was to focus on the efforts of persons attempting to enhance public health by analysing why they failed to implement preventive health measures (Carpenter, 2010). In a situation where there is still no effective vaccine available, keeping good environmental and personal hygiene are significant as domestic preventive measures. People should practice frequent hand washing and sanitising household surfaces by means to prevent virus shedding (Chan, et al., 2017). Social distancing is likewise recommended to prevent disease spread such as isolating infected children, keep them away from crowded places, less group activities and avoid sharing things with others (Del Valle et al., 2005). Despite that, infected children should be quarantine at home, resulting of

absenteeism in school or kindergarten at least seven days. In the time of outbreak, it may cause school closures, and this could be a burden for working parents and caregivers. Sim et al. (2014) reviewed literatures on the use of facemasks as a preventive measure in preventing airborne infections during epidemics. They stated that perceived susceptibility seemed to be the most important factor determining mask-wearing compliance. There should be more awareness on respiratory illnesses to increase the public's perceived vulnerability. Othman et al. (2019) also applied HBM in their study on dengue epidemic in Selangor.

A number of studies have applied health belief and preventive behaviour in HFMD area. Ma et al. (2011) assessed the effectiveness of public health measures such as school closures and cleanliness campaigns in reducing HFMD between year 2003 and 2009 in Hong Kong. Study in Bangkok by Charoenchokpanit and Pumpaibool (2013) showed a positive correlation between behaviour with knowledge and attitude among caregivers on HFMD preventive behaviour. Zhuang et al. (2015) listed the characteristics of HFMD that could help in disease prevention. Continuous detection and surveillance, including meteorology and social factors could help in HFMD incidence prediction and disease prevention. Zhang et al. (2016) focused on hand-washing routines as an effective preventive measure in halting HFMD among children in China. Children should be educated on the correct method on handwashing. Liu et al. (2019) studied the impacts of a large-scale hand hygiene intervention on self-reported behaviour as well as the underlying social cognitive implications in kindergartens, China. Their proposed strategy was to reduce HFMD among Chinese kindergarten children. Looking at taking vaccination as part of preventive behaviour, Qi et al. (2019) claimed that parents' knowledge of HFMD was insufficient, and nearly half of them were unwilling to vaccinate their children with the EV71 vaccine. Their findings highlighted the importance of additional efforts by Chongqing health officials to promote the acceptance of the EV71 vaccine,

particularly among parents of preschool children with lower education levels. Recently, Wang and Pang (2022) studied on HFMD during the COVID-19 pandemic and revealed potential gaps between positive information and attitudes toward preventative interventions and their actual adoption levels in families and childcare centres. Their findings highlight the need of continuing to promote HFMD prevention practises in households and childcare centres, especially during pandemics.

In Malaysia, Sulinam et al. (2017) looked at the relationship between HFMD prevention practises and sociodemographic, knowledge, and health belief factors, as well as the predictors of HFMD prevention practises among mothers with preschool children in Klang District. Similarly, Hamirudin et al. (2021) found moderate positive correlation between health belief, relationship factor, and community factor and preventative practises behaviour towards HFMD among caregivers in Petaling. Recently, Rajamoorthy et al. (2022) used HBM to examine preventive behaviours for HFMD among parents in Selangor, Malaysia. The findings implies that parents saw their children as a vulnerable category for the HFMD. This causes parents to take precautionary measures in order to keep their children from becoming infected with HFMD. Shahar et al. (2022) also used the HBM in attempts to improve parents' beliefs of susceptibility, severity, advantages, and barriers to their children's handwashing practise among preschool children in Malacca, Malaysia.

Furthermore, human behavioural changes can be triggered by chaotic responses motivated by risk perception and illness fear, in addition to those enforced by public authorities (eventually of unknown fatality). Many health behaviours change theories rely on risk perceptions, or an individual's perceived susceptibility to a hazard. Recent research suggests that interventions that successfully engage and change risk perceptions result in subsequent gains in health behaviours. Therefore, study in risk perception became essential in human behaviour study. Introduced by Slovic (1987), he studied on factors such as family history that provided some relevant

information about real illness susceptibility, other important information also plays a role in risk perception development. Risk perceptions, for example, are frequently influenced by the frequency with which a threat is conveyed in media exposure. Behaviour response played a relevant role during the early stages of the pandemic (Merler et al., 2008) and Jones and Salathe (2009) investigated on risk perception caused by exposure to massive information.

Individuals perceive a larger risk of disease when someone in their family has been diagnosed with a disease as studied by Chen and Kaphingst (2011). They examined the associations between lung cancer family history and risk perceptions. Ferrer and Klein (2015) reviewed published literature on risk perceptions and health behaviour, including research on risk perception formulation, risk perception types (including cognitive, emotional, and experiential), risk perception accuracy, and correlations and interactions among risk perception types. Liao et al. (2018) examined parents' risk perceptions and protective responses on HFMD cases among their children in Hong Kong. Risk perception was measured on their level of worry based on their child's situation. Herrera-Diestra and Meyers (2019) stated that individuals continuously assess risk in real time and decide whether or not to implement the intervention based on either direct knowledge of infected friends and family (number or fraction of infected social contacts) or indirect information about population-level prevalence, possibly obtained through news media. In order to understand individuals perceive risks and communicate about the effectiveness of protective measures, Abdulkareem et al. (2020) used an agent-based model improved by machine learning to investigate the effects of intelligent learning on the gradient from individual to collective learning. Abdelmagid et al. (2022) reviewed the existing research on risk perceptions of epidemic-prone diseases among the general public and health professionals in high-risk nations. They also looked at how researchers in various situations conceptualised and measured risk perception.

2.4 Game Theory in Forecasting Behaviour

Since 1944, game theorists pioneered by von Neumann and Morgenstern have developed formal theory about coalition behaviour. Behavioural game theory investigates how social preferences, social utility, and other psychological aspects influence people's strategic decision-making behaviour (Murnighan, 1978). Game theory is a mathematical approach to modelling behaviour that examines the strategic decisions of interacting parties. Behavioural game theory expands classical (analytical) game theory by considering how players feel about the payoffs received by other players, limitations in strategic thinking, the importance of context, and the consequences of learning (Camerer, 2003). Additionally, game theory is used to model situations where people need to make decision in the face of uncertainty or called players. The players will try to optimise their profit called pay-off by selecting available actions, named strategies. Games are typically about teamwork or justice. The Prisoner's Dilemma, Ultimatum Game, and Dictator Game are all well-known instances (Thaler, 2015). A recent study published by Zhao et al. (2015) studied an approach for modelling the dynamics of infectious diseases that incorporates information transmission, contact networks, and human behaviour changes. A spatial evolutionary game was used to investigate the impact of changes in human behaviour on the dynamics of disease transmission. Later, Zhao et al. (2018) developed the traditional SIR model in meta-population level based on the notion in the cited model, validated the coherence of the results between these two models, and further extended the model to consider possible impacts on long-distance travel, spatial-temporal analysis, and memory/forgetting influences connected to risk perception.

A number of studies focused on vaccination decision using the game theory framework. Bauch et al. (2003) provided a game theory and epidemic modelling synthesis that formalises the conflict between self-interest and group interest and demonstrates that voluntary vaccination is unlikely to achieve the group-optimal level.

This deficiency leads to a significant increase in predicted mortality following an attack. Later, Bauch and Earn (2004) explored the interplay between individual vaccination decisions and population-level mechanisms that determine vaccine uptake and herd immunity for an endemic illness, keeping in mind that inaccurate risk perception has a substantial influence on vaccination decisions. Bauch (2005) then extended his previous study by studying the relationship between vaccine coverage, illness prevalence, and individual vaccination behaviour. Furthermore, due of herd immunity, there is a strategic interaction between individuals when determining whether or not to vaccinate, because the likelihood that an individual will become infected depends on how many other individuals are vaccinated. Shim et al. (2009) created a game theoretic age-structured epidemiological model of rubella transmission and vaccination to assess how the balance of these parameters resulted in optimal vaccine coverage. They discovered that high levels of vaccination for both genders maximise average utility across the community by lowering the risk and minimising rubella transmission. Bhattacharyya and Bauch (2011) adopted “wait and see” approach to vaccinating during a pandemic using game theoretic analysis. Their study implied that providing accurate and useful vaccine safety information for a new vaccine before and during a pandemic outbreak is essential. Based on game theory, Kabir and Tanimoto (2019) presented the notion of social learning on a local time scale and proposed a unique theoretical framework for a vaccination game combined with the Susceptible-Vaccinated-Infected-Recovered (SVIR) epidemic model.

However, besides vaccination, quarantine of exposed individuals and isolation of infectious individuals are two of the most often used infectious disease control techniques. Numerous mathematical modelling studies have been conducted to evaluate the effectiveness of quarantine and isolation in preventing the spread of communicable illnesses in both animal and human populations. Day et al. (2006) indicated that the number of illnesses avoided using quarantine is quite low, assuming