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Managing Epidemic and Natural Disaster using Mathematical Modelling

DENGUE OUTBREAK: A SYSTEM DYNAMICS APPROACH

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Abstract

Dengue is an endemic disease that occurs across Malaysia with a large number of fatality cases being recorded each year. The Ministry of Health Malaysia has came out with the national dengue strategic plan in controlling the disease outbreak. Therefore, this study aims to develop a system dynamics model of dengue to help policy makers in simulating the effectiveness of the public health intervention. Simulation model can show the successes and failures of past policies, as well as predicting the consequences of selected policy proposals before their implementation. From this, future research can be done in order to enhance the existing intervention or to prompt new strategy in overcoming the problem.

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1.0 Introduction

Dengue is an endemic disease that occurs across Malaysia with a large number of fatality cases being recorded each year. It is a viral disease carried by mosquitoes. There are five types of dengue virus stated by World Health Organization (WHO) namely DEN-1, DEN-2, DEN-3, DEN-4 and DEN-5. The severe cases such as dengue fever (DF) and dengue hemorrhagic fever (DHF) can cause fatal illness that require hospitalization.

In Malaysia, the early reported cases of DF and DHF were reported in 1902. Ever since the first dengue outbreak, the number of dengue cases continues to grow. Contributing factors for increased dengue cases are mobility of population, serotype shift, climate change, poor environmental sanitation, human behavior and ineffective vector control.

In 2009, The Ministry of Health Malaysia (MOH) came out with the national dengue strategic plan to prevent and control the disease outbreak. The strategies include dengue surveillance, national cleanliness policy and Integrated Vector Management (IVM), management of dengue cases, social mobilization and communication for dengue, dengue outbreak response, dengue research and reduction of dengue burden in the Klang Valley. Despite the rigorous efforts, the infected people remains increase.

Therefore, this study aims to develop a system dynamics model of dengue to help decision makers in simulating the effectiveness of the public health intervention. Simulation model can show the successes and failures of past policies, as well as predicting the consequences of selected policy proposals before their implementation. From this, future research can be done in order to enhance the existing intervention or to prompt new strategy in overcoming the problem.

2.0 Problem Statement

Reported by the MHO, the incidence rate of dengue increases from 69.6 in 2011 to 396.4.0 per 100,000 population by the year 2015. The same trend is spotted in case fatality rates that went up from 0.18% to 0.28% between the same years as shown in Fig. 1.

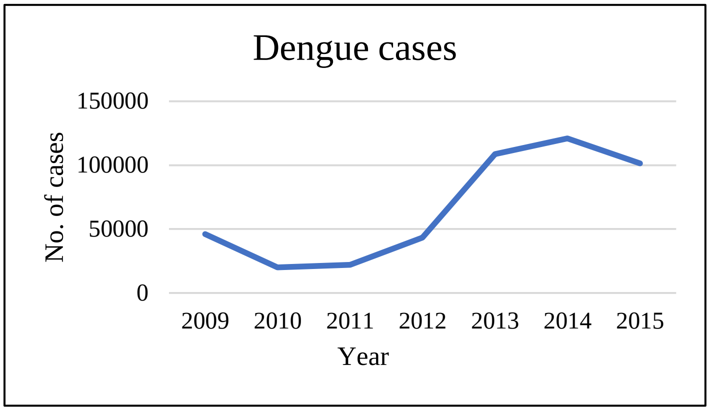


Figure 1: Dengue trend in Malaysia

Source: (The Ministry of Health Malaysia, 2017)

The impact of dengue can be felt at both an individual and a societal level. The illness caused a psychological and financial burden to the patients and family due to expensive treatment cost. Strain is felt by the health care services because of the sudden and high demand during epidemic. It was estimated in 2005 that dengue costs $13 million in treatment and vector control. A study by the Indian Institute of Management (IIMA) in 2009, the comparative costs to economies in the region put the financial burden of the virus on Malaysia at $5.3 per person, with total lost more than $153 million every year.

3.0 Objectives

This study aims to develop a system dynamics model of dengue to help decision makers in simulating the effectiveness of the public health intervention in line with the following objectives:

1. To predict the number of people infected by dengue
2. To predict the number of fatality causes by dengue
3. To identify possible intervention to reduce the number of infected people

4.0 Methodology

4.1 Identifying Key Variables

There are a number of study have been done to understand the underlying causes of dengue. Based on that, a few important factors are highlighted and used as variables in this study. The variables are classified into three groups, which are exogenous, endogenous and excluded. Table 1 shows the list of variables.

Table 1: List of variables

Endogenous	Exogenous	Excluded
Growth	Growth rate	Vector's population
Population	Death rate	Climate
Death	Incidence rate	
Infected	Recovery rate	
Infected people	Fatality rate	
Recovered	Factor rate	
Fatal	Population factor	

4.2 Data Collection

Data is obtained from the website of Ministry of Health Malaysia and Department of Statistics Malaysia. Data involve in this study are dengue cases, fatality rate and population of Malaysia. The data is collected between the year 2009 until 2016.

4.3 The System Dynamics Model

Known as a computational model, a simulation model is one in which a model is driven by suitable inputs and produces corresponding outputs (Axelrod, 1997). There are five steps in system dynamics modelling process known as problem articulation, formulation of dynamic hypothesis, formulation of simulation model, testing and policy design and evaluation. Problem articulation is where the data and issue regarding dengue is gathered.

Next, a causal loop diagram (CLD), referring to Fig. 2 is constructed to better understand the relationship among variables. Identifying feedback loops from the diagram may help to explain behaviour or to generate insights (Coyle, 2000). By understanding the feedback loops at play in the development of dengue, policy makers can work out with more successful interventions to combat the dengue problem. After that, the CLD is translated into a simulation model shown by Fig. 3 by using Vensim Personal Learning Edition (PLE).

The developed model is then validated based on dimensional consistency and extreme condition test. These tests look at assessing the model's robustness, as the model should behave in a realistic manner no matter how extreme the inputs or policies imposed on the model are (Sterman, 2000). The simulation result is compared to the actual data to ensure that the model is reliable to represent the real dengue system. Lastly, the model is used for policy design and evaluation.

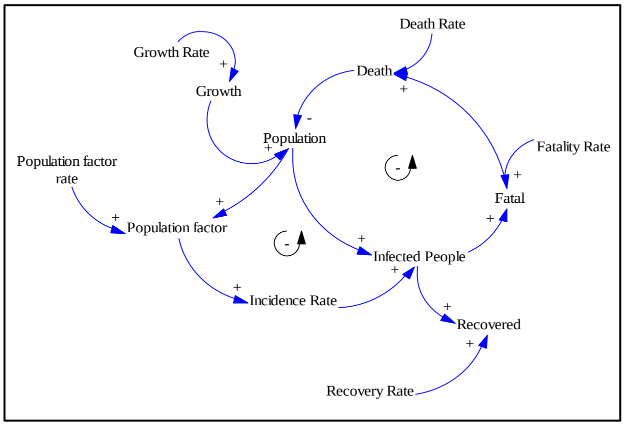


Figure 2: Causal loop diagram

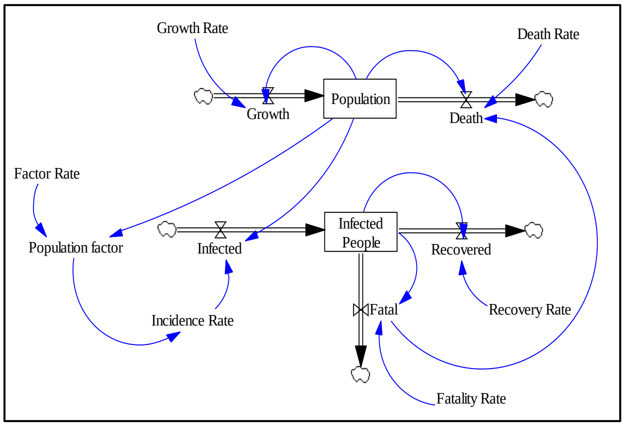


Figure 3: Stock flow diagram

5.0 Results and Discussions

5.1 Baseline Findings

By comparing the simulation result and the historical data, it can be concluded that the model behave according to the real system as presented in Fig. 4 and Fig. 5.

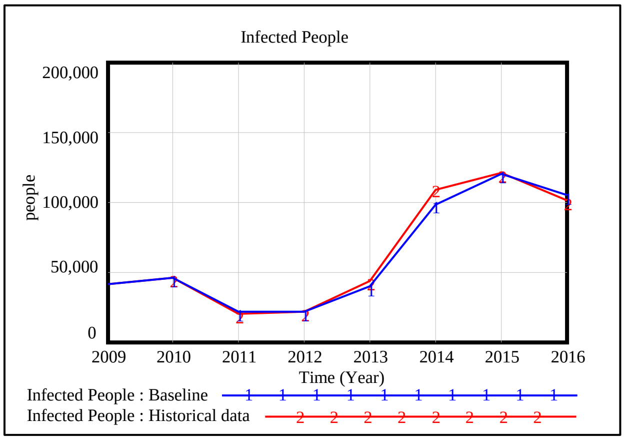


Figure 4: Behaviour of variable Infected People

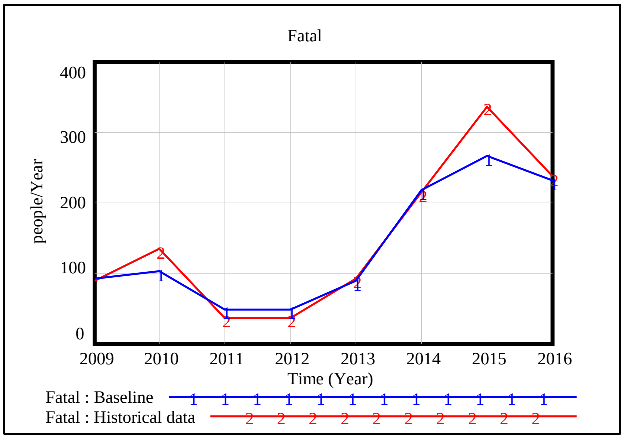
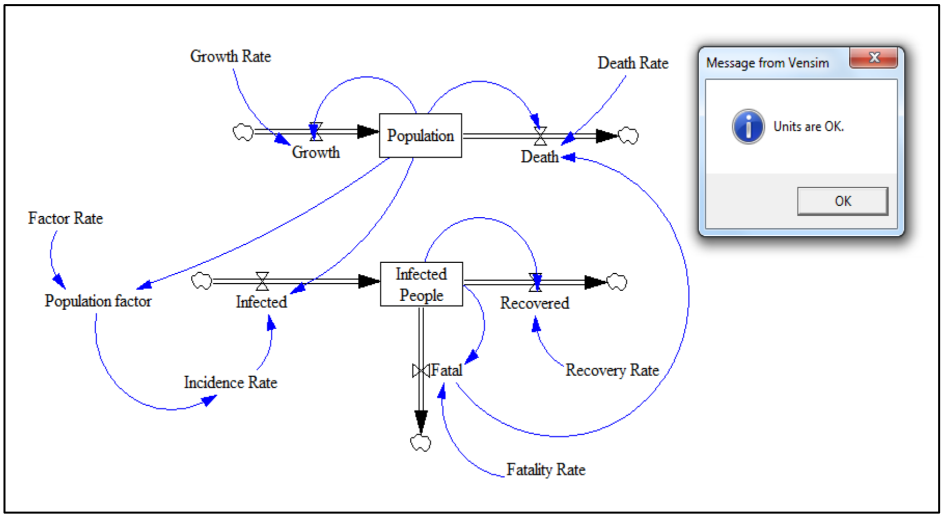


Figure 5: Behaviour of variable Fatal

5.2 Validation Result

5.2.1 Dimensional Consistency

The Unit Check function of the Vensim software is used to check for unit consistency. The model does fulfill the dimension consistency according to Vensim as displayed in Fig. 6.



Units are OK.

Figure 6: Result of dimensional consistency test

5.2.2 Extreme Condition Test

The extreme condition test performed for the infected people and fatal variable to assess the robustness of the model when the inputs take on extreme value. Value for recovery rate is set to zero to perform this test. When the recovery rate is equal to zero, we expect to see an increasing trend on both infected people and fatal variable. Based on the output shown by Fig. 7 and Fig. 8, it can be conclude that the model passed the extreme condition test.

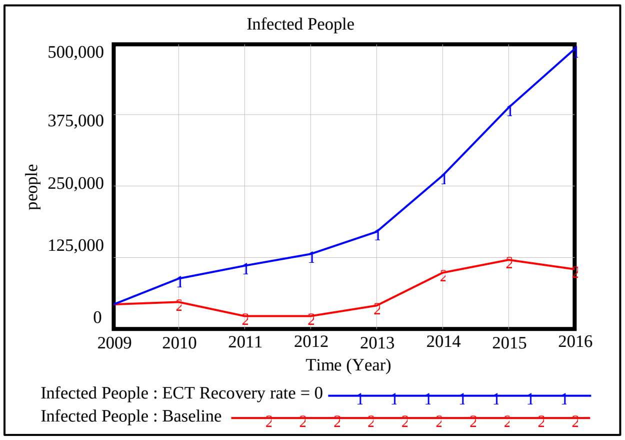


Figure 7: Extreme condition result: Infected People

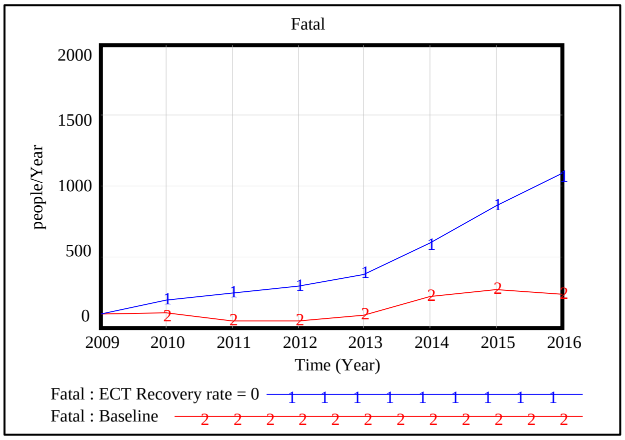


Figure 8: Extreme condition result: Fatal

5.3 Policy Intervention

According to the U.S. Centers for Disease Control and Prevention and the American Mosquito Control Association, the airborne spraying of pesticides, commonly called mosquito ‘fogging’ can help in controlling vector’s population thus decreasing the incidence rate of dengue.

Referring to Fig. 9, the baseline model is altered by adding the fogging variable as intervention to the model. The new model is simulated and the result is compared to the earlier baseline result. Based on the observation as shown in Fig. 10, a decreasing trend of infected people is seen.

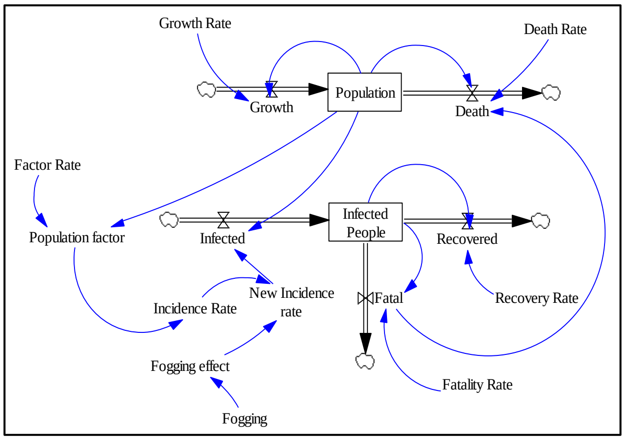


Figure 9: Stock Flow Model: Intervention

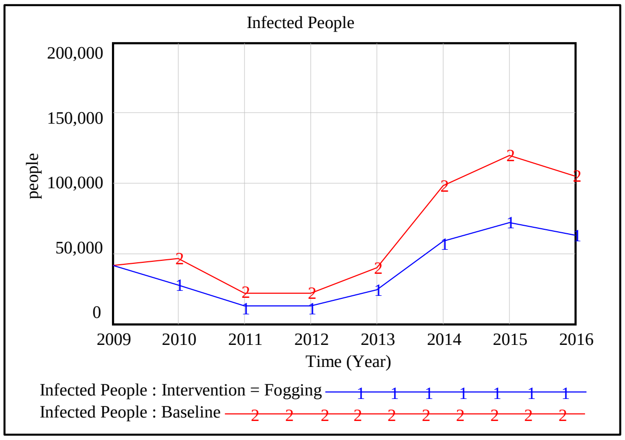


Figure 10: Result of intervention: Infected People

5.3.1 Implication of the Intervention Towards the Managerial Decision Making

Government need to provide a budget for fogging as it will incur some cost for the insecticides, fogging machine and hiring control operators. Furthermore, according to Lam (1993) in his study, the following problem aroused during the process:

1. Some house owners tend to close the doors and windows during fogging which will reduce the effectiveness of the spray droplets reaching the target mosquitoes.
2. Existence of synthetic insecticides for fogging which are not effective in controlling outbreaks.

3. Inadequate supervision to monitor the control operators when fogging is conducted.

6.0 Conclusion

The aim of the system dynamics model of dengue is to help decision makers in simulating the effectiveness of the public health intervention. Based on the findings, it can be conclude that the model is able to demonstrate the real dengue system as well as generating reliable result. However, there is improvement can be done to the model by including other important variables such as vector's population and climate change. By doing this, policy makers will be provided with a wider range of options regarding policy interventions.

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