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Research paper

Integrated Dynamical Model for Malaysian Solid Waste Management Using System Dynamics

Faridah Zulkipli[1], Zulkifli Mohd Nopiah[2], Noor Ezlin Ahamad Basri[3], Cheng Jack Kie[4], Jafri Zulkepli[5] and Khairul Irwan Khalid[6]

[1]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA Perak Branch, Tapah Campus 35400 Tapah Road, Perak, Malaysia
[2,3]Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 39000 UKM Bangi, Selangor, Malaysia
[4]Faculty of Industrial Management, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia
[5]School of Quantitative Sciences, College of Arts and Sciences, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia
[6]Perbadanan Pengurusan Sisa Pepejal and Pembersihan Awam (SWCorp) Kementerian Kesejahteraan Bandar, Perumahan Dan Kerajaan Tempatan, Blok J, MKN Embassy Techzone, Jalan Teknolokrat 2, 63000 Cyberjaya, Selangor, Malaysia
Corresponding Author Email: faridahzul@tmsk.uitm.edu.my

Abstract

Solid waste management is considered as one of the complex and dynamics problems worldwide due to rapid population, changing life style, urbanization process towards sustainable development and uncontrollable increment in solid waste generation. An efficient performance of solid waste management is depending on systematic strategic planning. The aim of this paper is to develop an integrated dynamical model to simulate the complexity of solid waste management in Malaysia. System dynamics as one of optimization methodology is applied in order to illustrate the continuous process in solid waste management Malaysia. As a result, an increasing trend of solid waste generation over time. By 2025, it is forecasted that total waste will be more than 15 million tonnes. Based on developed proposed model, the main factor to solid waste generation is population. However, in order to reduce the total solid waste, we cannot simply reduce the population Therefore; further actions are needed in order to reduce the total solid waste generation. The proposed model is capable of assisting the decision maker to determine the effectiveness of solid waste management practices especially in strategies planning and system design improvement.

***Keywords*:** optimization, system dynamics, continuous simulation, solid waste management

1. Introduction

A systematic solid waste management (SWM) planning and design especially in urban developing areas is vital. It requires an optimization empowerment in decision making process. SWM provides a huge challenge in the national development plans for developing countries including Malaysia. Experiencing rapid increase on the population and urbanization process reflects the increasing waste generated [5]. Abundant of solid waste generation from our daily activities has risked for our communities [22]. Based on Malaysian statistics, the data show that the Malaysian population especially in urban areas has dramatically increased to more than 50% for the last few decades [17] . Moreover, these rapid processes have relatively changed the characteristics of the Malaysian solid waste generation and the demand for a better quality of life among Malaysians [18]. The efficiency of future planning of solid waste management in order to achieve sustainable development has been affected by inadequate data and information on waste generation [21].

Solid waste generation in Malaysia has reached a dynamic perspective mainly on the amount of the solid waste generated and the composition of solid waste (. Rapid development, urban migration and life style changes reflected an increment of 3% to 4% annually on the waste generation rate ([2]; [18]). This is due to the fact that this transition process has changed the Malaysian solid waste management characteristics [9]. Consequently, an effective and systematic solid waste management approach needs to be apprised to suit the current solid waste quantity and composition. Committed response perceived from the Malaysian government in order to improve the quality of life for its citizen. Moreover, one of the crucial factors that have been influencing the quality of life in urban areas is through a series of systematic and effective solid waste management approaches. The government started to look for a systematic and effective solid waste management by introducing numerous of plans and strategies. For instance, the government has authorized its pledge of considering a sustainable development. As a result, the Malaysian government has announced that the generation of the national solid waste will be reduced in 2020. Therefore, enhancing solid waste management is one of the main strategies that are essentially emphasized in order to achieve this goal [11].

The application of system dynamics in solid waste management particularly for Malaysian context has not yet been established. The advantages of using system dynamics are this method is designed for catering with linear and non-linear interactions, large-scale of problem, complex environment and dynamic

scenario. Due to these advantages, therefore this study is the first to embark system dynamics for developing an integrated dynamical solid waste management model. System dynamics is a continuous simulation technique which is one of an alternative optimization in decision making process.

2. Material and Method

2.1 Solid Waste Management in Malaysia

The Solid Waste Corporation (SWCorp) under the Ministry of Urban Wellbeing, Housing and Local Government generally defines the Malaysian solid waste to include any scrap material or other unwanted surplus substances or rejected products rising from the application of any process; any substance required to be disposed of as being broken, worn out, contaminated or otherwise spoiled. The sources of solid waste are diverse, such as from the residential, institution, commercial, industry and others [12]. These wastes can be categorized based on its physical compositions [1] such as either organic (food waste, garden waste, textile, rubber and paper) or inorganic waste (plastic, glass and metal).

Malaysian solid waste has high moisture content [9] due to its climate change and which will apparently reflect the environment and the lifestyle of the Malaysian population. The highest waste composition consists of organic waste of approximately 50% such as food waste and garden waste. It is then followed by paper and plastic waste, which is more than 30% due to the high daily consumption rate [12]. The quantity and characteristics of the solid waste generated is very significant in the planning phase [19]. However, most of the previous studies on waste generation and waste characteristics are based on the solid waste collected and disposed in landfills. In the contact of Malaysia, limited and uncompleted documentation of the data regarding this solid waste generation is still low as compared to the developed countries such as European countries [9]. The solid waste generation in Malaysia was estimated about 33000 tons in 2012

The solid waste management process in Malaysia begins with the separation waste at the sources. This process is officially implemented in September 2015 under the supervision by the Solid Waste Corporation for the waste minimization campaign as well as to increase the public awareness on protecting the environment for future population sustainability. The difference between the waste generated and discharged must be carefully considered in order to identify the actual amount of waste generation. Not all the materials for which the generator has no further used for own purposes are discharged. The general flow of waste generation and discharging is illustrated in Figure 1. The process begins with the waste generation from the sources such as household, commercial, institutions and others until the waste disposal serves as the final process. Thus, the decisions in the area of solid waste management are not only capitally intensive, but they are also difficult to make from the environmental and social points of view. There is a necessity to develop, master and implement a simple but reliable tool that will help the decision makers in the analysis process. The integrated solid waste management model is an instrument to fulfil all the outlined requirements.

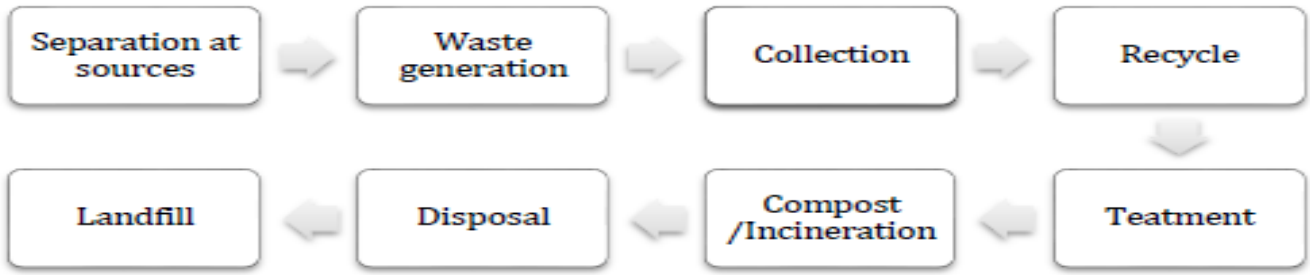

Fig. 1: Process Flow of solid waste management process in Malaysia

2.2 System Dynamics Methodology

Jay Forrester introduced system dynamics in the1960s at the Massachusetts Institute of Technology as a modelling and simulation methodology for the long-term decision-making analysis of industrial management problems ([4]; [14]; [10]). System dynamics is a quantitative method that particularly suited to the continuous behaviour by simulating of complex systems. It is qualified of dealing with the assumptions about the system structures in a rigorous fashion, and specifically of monitoring the effects of changes in the subsystems and their relationships ([14]; [10]). Moreover, it is also capable to representing the changes and rendering them transmissible. The system dynamics methodology is presented in Figure 2. System dynamics modelling has been used to address practically every sort of feedback system, including the business systems, ecological systems, social-economic systems, agricultural systems, political decision making systems, and environmental systems [6].

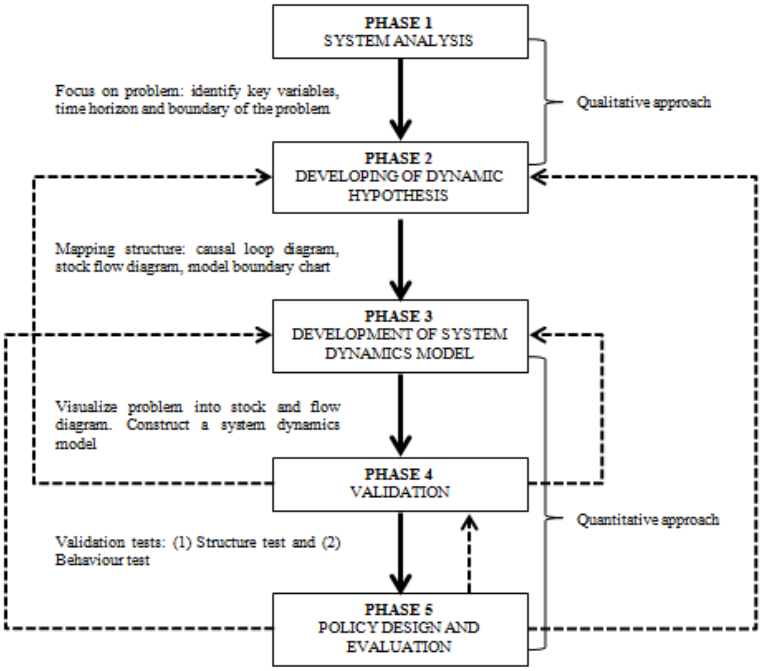

Fig. 2: System dynamics methodology

2.3 Solid Waste Management Model Using System Dynamics

The prediction of waste generation is a major concerned in waste management. The traditional forecasting approaches often count on the demographic and socioeconomic factors on a per-capita basis. In order to forecast the solid waste generation of a complex waste management system, a system dynamic model has been proposed. [6] have developed system dynamics models to forecast the solid waste generation in a town setting with a high economic growth potential. The authors developed the models based on the simulation of different combinations of factors that influence solid waste generation. For instance, they are (1) total income per service centre; (2) people per household; (3) historical amount generated; (4) income per household; and (5) population.

[8] developed a methodology to blend qualitative variables such as voluntary recycling participation and regulation impact quantitatively to forecast solid waste generation. [15] were engaged in a system dynamics model to seize the dynamic nature of interactions among the various elements of urban solid waste management system in a typical metropolitan city in India. The model has provided a platform for debate on the potential and systemic consequences of various structural and policy alternatives for sustainable solid waste management. The model was developed based on a feedback theory about the human behaviour and public policy that stresses both the importance of contextual and personal factors.

Previous studies have shown that using system dynamics methodology will help the policy makers to see the holistic views of solid waste management. This is due to the fact that in order to reduce the waste, they also need to see the variables that are linked together that make the complete system. This type of methodology that falls under simulation umbrella will also help the policy maker to play with multiple scenarios and see the impact if several variables and parameters have been changed. Based on the output, the policy maker can plan improvement in a short time compare using direct experimentation that will involve huge time and cost [20]. Using traditional statistic method also need an expertise to develop the model as the model needs to modified if some variables and parameter need to be changed, compared to system dynamics methodology. Based on the stated reasons, we plan to develop a generic model of waste management using system dynamics methodology.

To date, as far as we concern, there are no model that well represented current situation of Malaysian waste management that shows holistic processes of waste. The proposed model will demonstrate the interactive relation among factors in the solid waste management system in Malaysia. In this paper, we only discussed the generic system dynamics model of waste management in Malaysia and their result.

2.4 Development of Proposed Generic System Dynamics Model

The model is designed to initially assist the decision making process especially for Solid Waste Corporation (SWCorp), which is responsible authority in Malaysia for the management of solid waste with regard to the strategic planning purposes. The assessment allows the company in advance for the integration of the solid waste management to minimize the environment and socioeconomic impacts, caused by the increasing waste generation that is associated with the population growth. Constructing new landfills, exerting the effort to increase the recycling rate, composting rate, incineration rate and as well as separation waste at sources are one of the alternative decision options that can be executed by way of organizing an awareness campaign towards sustainable environmental balance ecology in future.

This developing process is on the preliminary stage that only shows the initial stage of the system dynamics methodology. The presented proposed integrated dynamical model enables modeller to illustrate the problem in a full presentation, which allows the manager of solid waste management to contribute an input cooperatively, which consists of the information and data collection. These will be used to validate and evaluate the proposed developed model.

Figure 3 is a proposed system dynamics model on the solid waste management based on the Malaysian perspective and current implementation process. The hypotheses about the influences are based on previous studies and each arrow in the diagram indicates an influence of one element on another. In this paper, we only focus on one factor that influences the waste generation rate, i.e. population. Logically, that the rate of waste is determined by

human, the increasing population will lead to increasing waste generation. All waste that has been collected will be send to garbage collection centre. At the collection centre, some of the waste will be divided into two types of waste, i.e. to landfill and recycle waste. The recycle waste will be processed and those unwanted waste will be send to landfill.

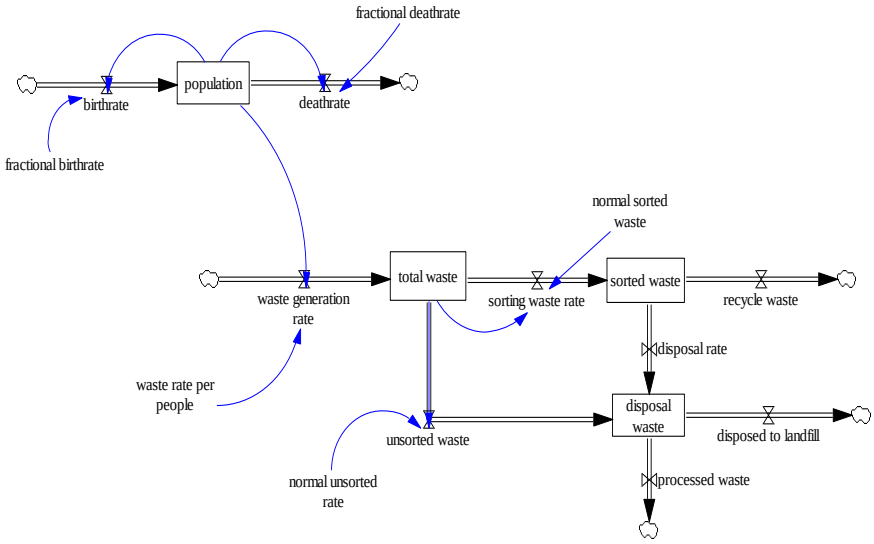

Fig. 3: Proposed System Dynamics model development for solid waste management in Malaysia

3. Results and Discussion

As in Figure 2 that depicted steps in developing system dynamics model, the model should be verified and validate to confirm that the developed model mimics current situation. There are several techniques that can be done to verified system dynamics model. One of them is behaviour reproduction test [13]. This technique allows us to compare simulation data with real data, i.e. reference mode. If the simulation data fit with real data, we can consider that the developed model is correct and mimics current condition.

We present the simulated behaviour of the total solid waste (line no 1) and the reference mode (line no 2 – data from SWCorp) as depicted in Figure 4. Based on the simulation and reference mode, we can conclude that the developed model is verified and validated correctly.

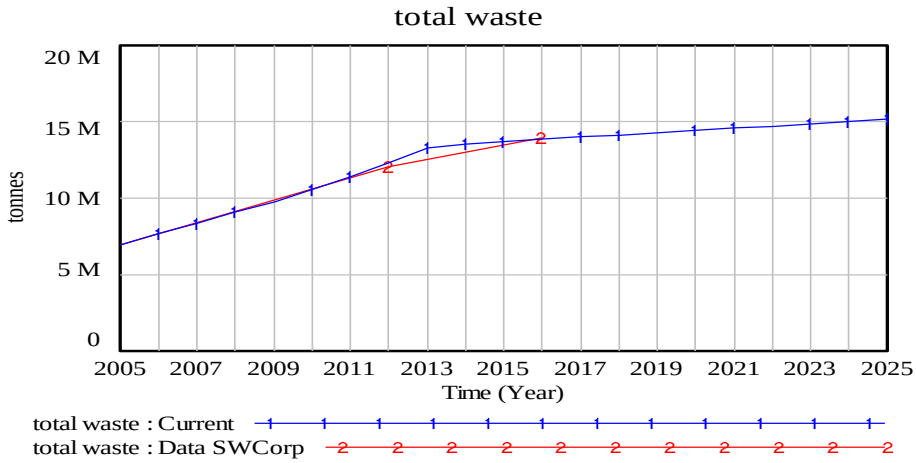

Fig. 4: Simulation and reference mode of total solid waste

Based on the result, we can see the increasing trend of total solid waste. By 2025, it is forecasted that total waste will be more than 15 million tonnes. Based on developed model, the main factor to solid waste generation is population. However, logically, in order to reduce the total solid waste, we cannot simply reduce the population Therefore actions are needed in order to reduce the total solid waste. By using the developed model, several interventions can be done within a short time. However, these interventions will be discussed in future work.

4. Conclusion

An integrated dynamical solid waste management model is developed and presented. The generic model mimics current practices in the solid waste management. Based on the result, an increasing trend of solid waste and thus, actions need to be taken to reduce the waste. This model is capable in assisting the decision maker in determining effective solid waste management practices especially for planning strategies and system design improvement. The developed model will further be extended with more variables to be included especially variables that play an active role in solid waste management. The advantages of using system dynamics methodology are capable for catering with linear and non-linear interactions, large-scale of problem, complex environment and dynamic scenario. Hence, this study is the first to embark system dynamics methodology in Malaysia to develop an integrated dynamical solid waste management model

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