SIMULATION ANALYSIS ON THE CONSEQUENCES OF BEHAVIOURAL CHANGE TOWARDS COMBATING OBESITY: SYSTEM DYNAMICS APPROACH

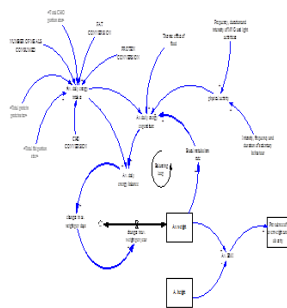Norhaslinda Zainal Abidin*, Jastini Mohd Jamil

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Graphical abstract

Abstract

Obesity is a medical condition where an individual has an excessive amount of body fat. Rapid development in industrialization and urbanization has brought changes to Malaysia's socioeconomic, especially on the diet and lifestyles of Malaysians. With this transformation, one of the impacts can be seen on weight. Thus, the aim of this paper is to simulate the effect of behavioral changes of eating and sedentary behavior on the population reversion trends of average weight. The model combines different strands of sub-models comprises of information from nutrition, physical activity and body metabolism and gathers into a weight behavior model system. Comparing the effect between improved diet or reduced sedentary behavior, this study reported that changing to healthy food consumption is a better prevention since it has been tested in the model. As a summary, this study highlighted the importance of focusing on both healthy diet and lifestyle as the best behavioral change strategy in developing guidelines to prevent obesity.

Keywords: Obesity, behavioral change, diet, sedentary behaviour, system dynamic

1.0 INTRODUCTION

Obesity is a condition in which an individual has developed an excessive of body fat and it is accumulated to the extent that it can lead to numerous health problems and decreases the quality and length of life [1]. Numerous studies have suggested that the best way of obesity prevention targeted at population should focus on behavioral perspective via changing to a healthy diet and lifestyles. The topic of behavioral influences on obesity, and its interaction process, is a unique topic for which conceptual frameworks are scarce.

Review of literatures highlighted that various behavioral change intervention studies have been conducted to find the solution towards weight loss and obesity prevention. Direct experimental approach or known as the randomized controlled trial setting usually has a real contact with people

and its environment. This approach emphasized more on understanding the complexity in people's experiences rather than obtaining information that can be generalized to the whole population [2].

Based on the analysis, the impact of intervention experimented to the specific group can be measured. This approach is restricted in terms of its implementation cost and longer period needed for the observed impact. For these reasons, it is necessary to search for an alternative for testing and experimentation purposes. Since obesity is a complex system, it will be beneficial to search for other techniques which may be offered through modelling methodologies that are more time and cost effective compared to direct experiment study.

The objective of this paper is to simulate the long term impact of behavioral change using system dynamics approach. Instead of predicting the future obesity levels, this study attempts investigate the influence of different configurations of action or

inaction [3, 4] that could alter the direction of obesity trends. This paper discusses the value of modifying either both sides of energy intake and expenditure to improve the population's body weight. System dynamics is a computer-based simulation approach which is widely used to model complex problems.

The remainder of this article is organized as follows: The next section review the literatures on both dietary intake and lifestyle behavior studies related to weight management and obesity prevention. The research methodology based on system dynamics modeling process is described in the following section. It is followed with the findings based on the analysis. The conclusion, limitations and future works are discussed in the final section.

2.0 LITERATURE REVIEW

2.1 Studies on the Elements of Behavioral Change on Weight and Obesity Prevention

Obesity is influenced by several factors including genetics. Being obese is a common genetic disorder as it is difficult to control genetics due to the needs of a human body. Apart from genetics, environments and behavior are two important factors that also contribute to obesity [5]. For this study, behavior is defined as an observable behavior which is frequently referred to risk factors that influence health performance such as smoking, drinking, diet, and exercise.

Various researches have studied the implications of different of dietary intake and lifestyle elements on weight and obesity. Some of these elements are presented in Table 1. This review discusses the value of modifying either one or both sides of energy intake and energy expenditure on physical measurement improvement related to obesity.

Table 1 Summary of selected studies which inspect the various element of behavioral change

Behavioral change	Element of interventions	Authors	
Dietary intake	Low fat diets	[6]	Carty, Looperberg, Neuhouser et al. (2010)
	Low carbohydrate diets	[7]	Nordmann, Nordamn, Briel et al (2006)
	Calories reduction (500-1000 kcal/day)	[8], [9], [10]	National Health & Medical Research Council (2013); 2006 Canadian Clinical Practice Guideline (2007); Klein, Sheard, Pi-Sunyer et al. (2004)
	Controlling the portion size	[11], [12]	Ledikwe et al. (2005); Young & Nestle (2002)
	Controlling the eating	[13], [14]	Leidy, Tang, Amstrong et al. (2011); McCrory,

Behavioral change	Element of interventions	Authors	
	frequency	[15]	Howarth, Roberts & Huang (2011); Bachman & Raynor (2012)
Lifestyle	Type of physical activity	[16], [17]	Bales, Hawk, Granville et al. (2012); Slentz, Bateman, Wills et al. (2011)
	Intensity of physical activity	[18], [19], [20]	Tremblay, Bouchard et al. (1994); Trap, Chisholm, Freund et al. (2008); Boutcher (2011)
Both behaviors	Sedentary behavior	[21], [22]	Robinson (1999), Epstein et al, (2005)
	Dietary restriction combined with physical activity	[23], [24], [25]	Klesges et al, (2008, 2010) Caballero et al, (2003)

2.2 Modeling Studies of Behavior Change Related to Obesity

From the context of modeling studies, an approach to imitate the real complex problem by building a mathematical model is needed. One of the suitable approaches is system dynamics (SD). SD is a simulation approach that allows the modeller to test and assess the impact of intervention in a long term period, compared to randomized controlled trial approach which is bounded with time and cost limitations [2]. By definition, SD is an approach to understand the structure, and the behavior of complex system over time based on stock, flow, and internal feedback loop explanation [26]. Generally, the aim of an SD model is to study the characteristics and behavior of the problem, and finally to draw conclusion and make actions based on the results of simulation.

There have been several outstanding studies on obesity which employed the SD approach. Abdel-Hamid [27, 28] assesses the interaction between dietary intake and exercise on the impact of adult's body weight and body composition. Specifically, the main focus of this work is to examine the implication of intensity of exercises on the amount and composition of weight loss. Furthermore, Homer and colleagues in 2004 simulate the impact of caloric imbalance on changes in body weight and BMI of adult population in USA [29]. Nonetheless, Flatt has also developed an SD model to explore obesity conditions from the nutritional perspective [30]. On the other hand, Homer et al. model the various BMI ages-range categories resulted from the imbalance caloric consumption among the population [31]. Finally, the model developed by Dangerfield and Abidin [32], and Abidin [33] focus on measuring children's total energy intake through incorporating the number of meals and portion size of meals

consumed at school, home and outside establishments in their model development.

## 3.0 METHODOLOGY

3.1 Data Collection

Since this study involve with simulation, there is no requirement of collected data from obese respondents on their eating and physical activity behaviour, and physical measurement. However, the main data for this study is collected from secondary source which considered applicable to develop the model. The purpose of any simulation model is to replicate the real problem structurally and behaviorally [26]. From SD point of view, a point-for-point fit is not required. However, the simulated patterns must be in line with real behaviour patterns. To reduce the bias between prediction and real data, other tests is employed such as extreme condition test as discussed in Section 3.4. This type of test is needed especially to overcome the problem with no available data. The aim of this test is to identify the possible deficiencies in the model.

The data in this study incorporates a four-year reports (1986, 1996, 2006 and 2011) obtained from the National and Health Morbidity Survey (NHMS). Information related to weight, body mass index (BMI), and prevalence of obesity of the adult population in Malaysia are derived from the reports. Simultaneously, data from articles review and informal discussions with nutritionist on the dietary intake and lifestyle information of the population are also incorporated in the study.

3.2 Model Framework

The framework for obesity behavior system focuses on energy intake, energy expenditure and energy balance, which is illustrated in Figure 1. According to Wlodek & Gonzales (2003) [34], weight gain is a result of excessive energy intake compared to energy expenditure or energy expenditure is less than energy intake. Contradictarily, weight loss is a result of lesser energy intake relative to energy expenditure. For weight balance, energy intake must be equal to energy expenditure.

Referring to this framework, energy balance is the center between energy intake and energy expenditure. Energy intake is measured based on carbohydrate, protein and fat that are consumed from fast food, home and outside sources. On the other hand, energy expenditure is measured via basal metabolism rate, physical activity and thermic effect of food sources. If the energy balance is positive, it will trigger weight gain. Conversely, weight loss is an outcome of a negative energy balance [34].
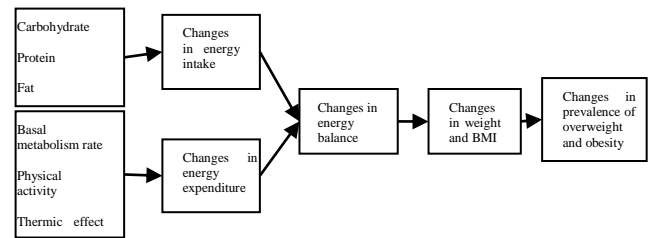
Figure 1 Framework on the impact of behavior change on the changes in physical measurement

3.3 Modelling Process

In general, SD involves five steps in modeling the obesity behavior as follows:

Stage 1: Problem identification- Problem is clearly defined based on the evidence collected of how behavior influence on obesity. Accordingly, the time horizon between 1996 and 2020 is specified to run the model. The model is specifically divided into phase 1 (1996-2015) and phase 2 (2016-2020) to represent the simulation of the past and future trends. Furthermore, data for weight, BMI and prevalence of obesity are gathered to develop a reference mode, which is the pattern of behavior that triggers the problem.

Stage 2: Dynamic hypothesis formulation - A conceptual model is constructed to explain the origins of the problem, in term of the underlying feedback structure of the obesity behavior system.

Stage 3: Model development - The developed conceptual model in Stage 2 is extended to a formal SD stock and flow diagram using Vensim software. The aim of this extended model is to formalize the structure of the problem, by inserting the equation to link the feedback variables to the unit inclusion.

Stage 4: Model validation - Several tests are conducted to assess the quality of the developed model. This is to represent the reality of the problem from the structure and behavior perspective.

Stage 5: Policy testing and evaluation- The model is used for policy design process and tested for improvement strategies.

SD modelling is an iterative process, as the stage is repeated if the developed model failed to mimic the real world problem from the structure and behavior context [4]. These steps involve both quantitative and qualitative approaches that are important in modeling real complex problems. Generally, SD which is based on differential equations, are most conveniently constructed using software. The stock and flow diagram for obesity behavior system incorporates the energy intake, energy expenditure and energy balance, which is presented in Figure 2.
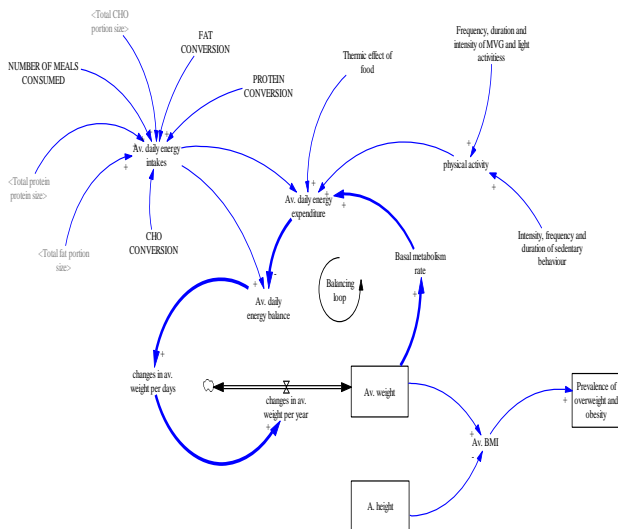
Figure 2 Causal loop diagram on the dynamic interaction between eating a nd physical activity behaviour on weight, BMI and prevalence of obesity effect

Basically, all SD model is developed based on stock, flow, parameter and auxiliary. By definition, stock is the accumulation of variables, while flows resulted as the changes in stock. Parameter is the constant value assigned to the model, while auxiliary is an intermediate variable linked to the variables [26]. The uniqueness of SD relative to other conventional approach lies is the feedback process. The influence factors are linked in a feedback loop process to explain the impact of changes in any variables on weight and BMI implications. Some of the important equations in the model are presented in the following equations:

Energy balance=energy intake-energy expenditure
Eqn .1

Average body mass index = Average weight/(Average height x Av. height)
Eqn. 2

Daily energy intake = [(Total CHO portion size x CHO conversion) + (Total fat portion size x fat conversion) + (Total protein portion size x protein conversion)] x (meals consumption)
Eqn. 3

Daily energy expenditure = Basal metabolism rate + Daily physical activity + Thermic effect of food calories
Eqn. 4

3.4 Model Validation

The model is tested with extreme condition test. This is to check whether the model behave in a realistic fashion when an extreme inputs are assigned to the model [26]. In this study, an extreme value of energy balance zero is assigned to the model. Theoretically, a balance weight is derived if the energy intake is equal to the energy expenditure, vice versa. [34]. Logically, the model should produce a continuous

trend, given that energy intake is equal to energy expenditure in an extreme condition setting to the model.

3.5 Policy Optimization

Model evaluation is conducted based on policy optimization approach. The concept of policy optimization in SD is based on payoff function and weight. The payoff function is a formula which expresses the objective function with weight value is assigned to the payoff function. The process continues to search for the best solution based on the considered parameters that resulted in best fit trends [35].

The aim of policy optimization in this study is to determine the best behavioral change strategy for the result of reversing the increased in weight trend with the greatest reduction. The highest reduction in this measurement is considered as the most effective solution. Basically, the other variables are maintained in the baserun model except for the listed parameters given in Table 2. All the experiment scenarios are made up to 50% change for standard comparison. All the tested parameters are assumed to commence in 2015. Alterations made in eating and physical activity parameters work by decreasing the amount of energy intake and increasing both physical activity energy and total energy expenditure.

Basically, changes in the behavior are the result of changes in both energy intake and energy expenditure which triggers changes in energy balance as illustrated in Figure 1. Greater reduction in energy resulted in highest weight reduction. The three types of behavioral change strategies tested in the model are shown in Table 2.

Table 2 Lists of parameters tested in the model (Note: C=combined; Min=minimum; Max=maximum)

Experiment Strategy	Description	Min	Max
1. Strategy1: Dietary intake	Reduce intakes of carbohydrate, protein and fat consumed from outside meals	0.01	0.02
2. Strategy 2: Sedentary behavior	Reduce the frequency and duration of sedentary behavior	0.006	0.09
3. Strategy 3: Combination of dietary intake and sedentary behaviour	Combination of the behavior	C	C

4.0 RESULTS AND DISCUSSIONS

4.1 Model Validation

Finding from the extreme condition test is presented in Figure 3. The graph shows that with zero energy balance (if the energy intake equal to energy expanded), the weight trend is maintained with initial value of 57kg in 1996 until 2020.
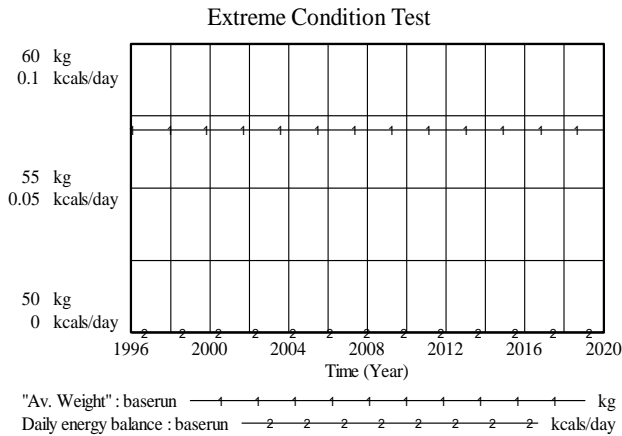

Figure 3 Finding on the extreme condition test with zero energy balance

4.2 Findings of Optimization Analysis

The baserun model shows that the increase in average weight trend is parallel to the growth in energy intake, starting from 1996 to 2020 as illustrated in Figure 4. Details of the analysed outputs for two periods of study (1996 and 2020) is presented in Table 3.
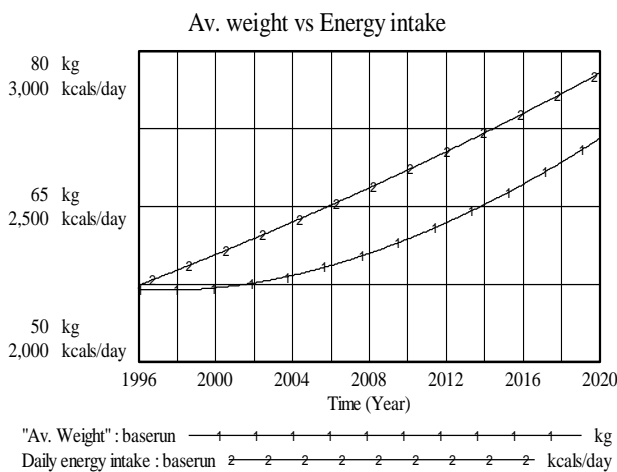

Figure 4 Behaviour trends on the energy intake implications on weight

This study highlights two important findings. First, the experiments revealed that a combination of behavioral change is the best strategy for weight loss since it attained the highest reduction in average weight as a whole, rather than looking at single aspects of dietary intake or sedentary behaviour. Overall, the percentage of change in average weight in 2020 derived from strategy 1, strategy 2, and strategy 3 are 0.48%, 0.3%, and 0.53% respectively. This finding is supported by studies done by Skender *et al*. [36], and Curioni and Lourenco [37] which reported that combination of both behavior change is the effective strategy to weight management, and obesity prevention.

Secondly, comparison between dietary intake and lifestyle intervention revealed that changing to healthy food consumption is a better preventing strategy which has been tested in the model. Referring to Table 3, weight is reduced to 0.48% through improvement in dietary intake relative to sedentary behaviour strategy with only 0.38% reduction.

Table 3 The comparison on the effect of the three intervention strategies on the weight reduction in year 2020

Experiment Strategies	Year/Measurement					
	2015			2020		
	Baserun	Weight	% of change	Baserun	Weight	% of change
Strategy 1	66.16	66.16	-	71.58	71.23	0.48
Strategy 2	66.16	66.16	-	71.58	71.36	0.30
Strategy 3	66.16	66.16	-	71.58	71.20	0.53

5.0 CONCLUSION

In this study, system dynamics approach is proven to be a useful approach to model and solve the complex obesity behavioral change issues. Specifically, the dynamic obesity model is successfully developed to incorporate the information from nutritional, physical activity and body metabolism and gathered into single simulation model of a human weight regulation system. Findings from this study highlighted that the design program for obesity prevention should focus both on practicing healthy eating and active lifestyle. Adopting a healthier lifestyle is not only beneficial to weight and obesity control but it is proven to combat the chances of getting complicated diseases such as diabetes and cardiovascular diseases [1].

Despite the useful findings, this study is still subject to improvements. First, the model can be expanded to incorporate the environmental factors that might have meaningful solution towards combating obesity. Second, the developed model should be tested rigorously in order to develop confidence in the model.

Acknowledgement

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