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Preventing Weight Gain through Tackling Sedentary Behaviour: A System Dynamics Optimization Approach

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Abstract

Obesity is becoming a serious problem in Malaysia as it has been rated as the highest among Asian countries. Many factors have contributed to obesity and sedentary behavior is one of the cause. The objective of the research is to analyze the impact of sedentary behavior to prevent weight gain among adult population in Malaysia. The system dynamics (SD) approach of stockflow diagram was used to quantitatively model the impact of eating and activity behavior on the complex of human weight regulation system. The modeling stage involved with the experimentation process where the developed model was used to investigate the impacts of changes in duration and frequency of sedentary behaviour on weight and prevalence of obesity implications. In this paper, the baserun results is presented where it shows that with increase in energy intake along with increase in sedentary behavior, the results is on weight gain. This is because the excessive of positive balance energy which accumulate in daily process will results to the increase in a weight trend for a long period if the excess energy is not burning.This paper provides evidence on the usefulness of SD optimization to assist in decision making related to achievement in population weight target. SD applied in this research is relatively new in Malaysia and has a high potential to apply to any feedback models that address the behavior cause to obesity.

Keywords: Obesity; Sedentary behaviour; System dynamics Optimization; Weight gain.

1.Introduction

Globally, many countries have undergone considerable socioeconomic transition with the rise in income and resulted to the increase in demand for food and induced changes in their lifestyles. Over the last two decades, Malaysian population consumed a high consumption of energy-dense foods supported with increased in sedentary behaviour due to the increasingly sedentary nature in many forms of work and changing modes of transportation (Noor, 2002). One of the impacts of this leisure lifestyle is on the development of obesity.

In medical term, obesity is defined as a condition where an individual has an excessive amount of body fat. Obesity was considered a sign of health, beauty, fertility and wealth long time ago (Eknoyan, 2006) and today obesity is the most conventional nutritional disorder and recognized as a chronic illness in most of developed countries. Evidence shows that obesity is not only the cause to various health problems, it also has an impact on the quality and lengthy of life (WHO, 2014).

In Malaysia, according to National Health and Morbidity Survey, 23% of Malaysians' adult were obese or overweight in 1996 and the percentage has increased to 43% in 2006 (Institute for Public Health Ministry of Health Malaysia, 2008). With the growing in percentage of obesity over the years, interventions of preventing weight gain across populations are urgently needed as the Malaysian Ministry of Health itself is concerned about the health effects, productivity and the health care cost implications of the obesity epidemic. Taking into account the current and emerging nutrition issues in the country, National Plan for Action for Nutrition (NPANM) was reviewed and NPANMII (2006-2015) was developed in tandem with the objectives and strategies of the National Nutrition Policy of Malaysia. The target is to achieve not more 20.8% the prevalence of obese among adults aged 18 years and above by Ministry of Health Malaysia in 2015 (Ministry of Health Malaysia, 2016). Realizing the seriousness of obesity issue in Malaysia, research is needed to suggest what are the strategies should be focus to achieve the population weight target to prevent our population from being obese, as the obesity can cause to numerous health and psychosocial problems including cost burden to the country (Kumanyika *et al.*, 2002).

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In most obesity prevention studies, randomized controlled trial is a scientific experiment where people being studied are randomly allocated in different treatments groups to measure the effectiveness of the treatment. Although randomised controlled trial is considered as the gold standard for measuring the efficacy of interventions, this method has limitations related to methodological and pragmatic concerns (Salmon *et al.*, 2005; Yitschaky *et al.*, 2011). Thus, modelling approach particularly simulation is the alternative method which can replicate the intervention of treatment with less cost and time taken to observe the impact. One of the simulation approaches is system dynamics.

In this work, system dynamics (SD) optimization modeling is adopted in measuring behaviour energy related to eating and physical activity. SD simulation is a modelling tool that can used for measuring the behavior energy by mimicking the similar energy trends with less time consuming, and less costly as explained in Jafri et al. 2014 (Zulkepli *et al.*, 2014). Generally, SD is a simulation tool which is applied to test policy, and to overcome policy resistance (Sterman, 2002). Limited number of SD obesity studies are reported in literatures (Dangerfield B. C. and Abidin, 2011; Homer *et al.*, 2004b; Homer *et al.*, 2006). Although these SD studies have a great contribution to obesity solution, no further analysis on the process of how the behaviour to the achievement in weight target has been discussed. Having this gap, the objective of this paper is to study the impact of changes made in sedentary behavior on the achievement of population weight desired target.

The arrangement of the paper is prepared as follows. Section II focus on the review of studies related to the impact of sedentary behavior on weight, and the application of SD in the field of obesity studies. Explanation on a framework diagram of obesity model is presented in the Section III. Afterwards, methodology of the research is discussed in Section V continue with the result of analysis in Section VI. Finally, conclusions of the study including limitations and future works are also offered in the last section.

2. Literature Review

2.1. Studies on the Impact of Sedentary Behaviour on Weight and Obesity Implications

By definition sedentary behaviour refers to activities that do not increase energy expenditure substantially above the resting levels (Pate *et al.*, 2008). Sedentary behaviours might include various of behaviour at work or school, at home, during transport and in leisure time including sleeping, sitting, lying down, watching television and other forms of screen-based entertainments. Transition occur in socioeconomic today through rapid development in industrialization and urbanization has brought changes to the lifestyles of societies where they are depending much on machines to perform daily work and sitting in front of computer at work place.

It is well-acknowledge in the literatures that sedentary behaviour is one of the responsible factors in obesity. Numerous studies have examined the associations between television watching and obesity. There is convincing evidence proven that the more time spent in watching television, the more likely they are to gain weight or become overweight and obese. For instance, a study by Shields and Trembley (Shields and Tremblay, 2008). which studied the effects of watching television on obesity reported that adults in Canadian who are watching television more than 21 hours per week and frequent computer users (more than 11 hours per week) are associated with obesity for both sexes. Another study showing that BMI and physical activity patterns are both associated with hours of television watched is studied by Salmon et al. (Salmon *et al.*, 2000). This study reported that in comparison with those participants who watching hours are less than one hour, those watching 1 to 2.5 hours are 93% more likely to be overweight (BMI>/=25 kg/m2), those watching 2.5 to 4 hours are 183% more likely to be overweight, and those watching more than 4 hours per day are four times more likely to be obese. Another study by Vioque, Torres and Quiles (Vioque *et al.*, 2000) analyses the relationship between obesity and its causes; TV viewing, sleeping time and phsycal activity at work by using multivariate analysis. The findings shows that people watching TV more than 4 hours per day showed a higher adjusted prevalence odds ratio of obesity, compared to those watching TV less or equal to 1 hour per day. People who reported to sleep more than 9 hours per day presented a lower prevalence odds ratio of obesity than those sleeping less or equal than 6 hours per day. Therefore, from the previous studies it has been proven that watching television is one of the major reason for overweight and obesity. This activity would discourage one from being active. The tendency to have poor nutrition such as fat food (Robinson *et al.*, 2001), and fast food and soft drinks (French *et al.*, 2001) is also increased through snacking while watching. Similarly for children, a review from Coon et al. (Coon *et al.*, 2001) observe this behavior among children. It is reported that children would consume more red meat, pizza and snack food while having their meals in front of television.

Other sedentary behaviour such as computer and/or internet use, video game playing and sitting at work also contribute to obesity. A number of studies suggested that high usage of the internet is associated with weight gain (Berkey *et al.*, 2008; Carvalhal *et al.*, 2006; Schneider *et al.*, 2007) although not all studies have found any impact (Rey-López *et al.*, 2008; Swinburn and Shelly, 2008). Similarly, some studies found evidence that spending too much time in sitting at work and home increases the chances of becoming overweight and obese and increased the risk of getting chronic diseases and early death (Grøntved and Hu, 2011; van der Ploeg *et al.*, 2012).

2.2. Studies on the Used of System Dynamics Approach in Obesity Studies

The behavior of obesity system can be studied through SD. SD is a computer-based approach that is first introduced by Jay W. Forrester to understand and analyze a system's behavior over time. Most complex behaviors usually arise from the interactions (feedback) among the components of the system (Sterman, 2002). The complex and dynamic problem can be studied with this method as the system can be applied to diverse fields of study such as healthcare (Abidin *et al.*, 2014b), strategic planning (Hawari and Tahar, 2015) and education (Altamirano and Van

Daalen, 2004). The traditional correlation method used in obesity study should preferably be replaced with SD approach as it takes deep interest on the causation of the problems and the evaluation of policies and long-term influence. The domain of SD is the ability to model and analyze the quantitative and qualitative study where this study focuses on the quantitative side of the obesity in Malaysia (Coyle *et al.*, 1999). Plus, SD will clearly define the causal relationship between sedentary behaviour and other factors in the system that is dynamic over time (Hellman, 1982). Thus, it can be assured that the use of SD in the study of obesity is suitable.

Numerous obesity studies using SD approach can be found in literatures. The study of Abdel-Hamid (Abdel-Hamid, 2002;2003) modelled the impact of dietary intake and exercise on adult's body weight and body composition. Homer and colleagues modelled the impact of caloric imbalance on the changes in body weight and BMI of USA adults (Homer *et al.*, 2004a).On the other hand, Flatt developed a model to study the impact of food consumption on weight and body composition (Flatt, 2004). Finally, SD model by Abidin *et al.* (2014b) measures children's energy intake with emphasized on the number of meals and portion size, and the role of physical activity on weight and obesity impact. Finally, a paper by Abidin *et al.* (2014a) simulated the effect of changes in eating behavior of English children whose ages ranged from 2 to 15 years on weight and obesity. This study identified on how long it will take to achieve the desired prevalence of obesity target.

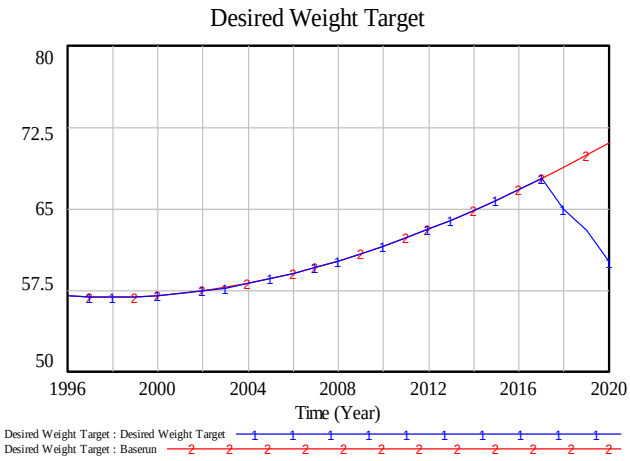
Even though supporting evidence have shown that sedentary behavior has an impact on weight gain and obesity, none of the mentioned studies is focused on leisure activity towards achievement of weight target. Acknowledging this gap, this paper simulated the impact of sedentary behaviour on the population weight target. In this study, SD of obesity model was developed to conduct various experimental scenarios to identify the potential strategies towards the achievement of desired weight target.

3. Problem Conceptualization

The weight trajectory was given in the base run in Figure 1. We determined on weight because for the nation to reverse the rising tide of population obesity is through ensuring absolutely everyone is capable to attain a healthy weight. Thus, the achievement in prevalence of obesity will be achieved.

The health analyst is uncertain that this trajectory can be continued for an extended period. Hence, we explore the dynamic that could lead to the decline in the pattern of population weight in the year of 2020. By studying these scenarios, the direction of obesity trends may be outlined under different configurations of both action and inaction. This study employs a holistic of system view where the different factors which influenced the overall performance system are highlighted in a holistic model. It is believed by having such tools, the analysis of the impacts of policy alternatives can be prevented from severe static, fragmented and inefficient. Moreover, inertia and resistance that are featured in all complex system might make one overlook important sources (Sterman, 2000).

Figure-1. Scenario of future behavior of behaviour of weight pattern



4. Methodology

4.1. Data Sources

In this research, data is obtained from National Health and Morbidity Survey reports, review of literatures and expert opinion. Data from literature include the relevant publications such as text books. Meanwhile, data collected from expert was used to validate the structure and behaviour of the model. For model assessment, several testing such as expert's validation and extreme condition test was used to check the structure and behavior of the developed model. Having the constraint of limited historical data, this research relies strongly on the similarities of obesity structure from the previous case studies (Abdel-Hamid, 2003; Homer *et al.*, 2004a) and the input from experts and literature review.

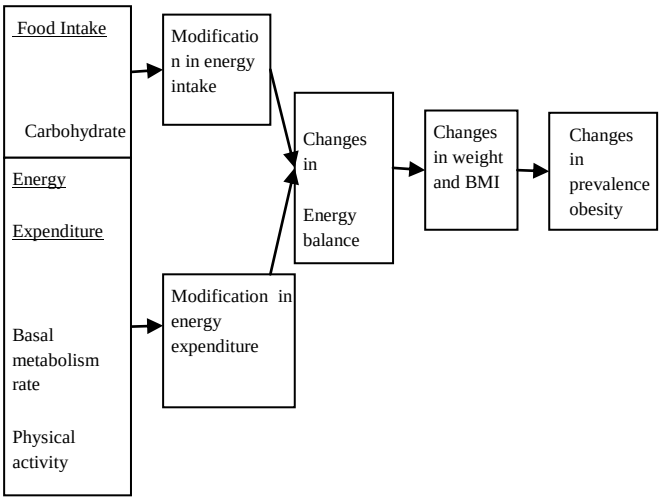
4.2. Framework of Obesity Diagram

Referring to Figure 2, the linkages between food intake, energy expenditure and physical measurement is centered to energy balance. According to Egger and Swinburn (1997), if energy intake is higher than energy expenditure or energy expenditure is less than energy intake it result to weight gain. However, weight loss is a result

if energy intake less than energy expenditure. For weight balance, energy intake is equal to energy expenditure. In this research, energy intake is measured from three nutrients called carbohydrate, protein and fat. These nutrients are consumed from fast food, home and outside sources. On the other hand, energy expenditure is measured from three sources namely basal metabolism rate, physical activity and thermic effect of food. The result is weight gain if the energy balance is positive while weight loss is an outcome from negative energy balance (Dangerfield B.C., 2009).

The framework offers an overall view to encompass the cause and impact of eating and physical activity behaviour on the human's weight, body mass index (BMI) and prevalence of obesity (POB). Develop understanding on the obesity development process, it can therefore shed light on potential intervention strategies that the authority should focus on. Basically, the fundamental cause of obesity is energy intake is higher than expended (Dangerfield B.C., 2009). Significantly, the standards of living have improved where the food availability has expanded and become more diversified and access to services has increased. Nevertheless, there have also been negative effects such as inappropriate dietary patterns and a decrease in performing physical activities.

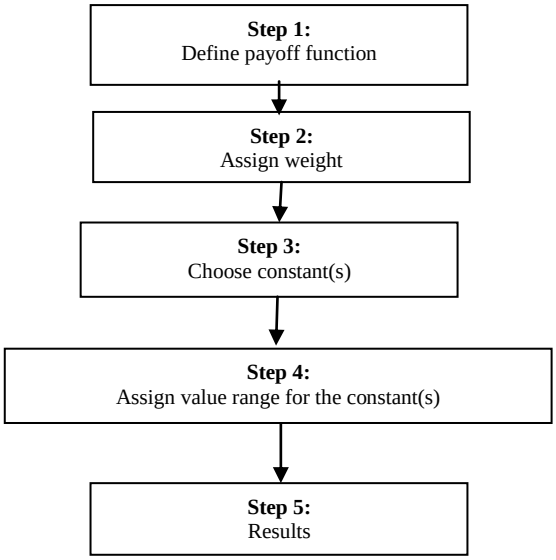
Figure-2. Framework on the impact of behaviors change on weight and prevalence of obesity implications



4.3. Steps in System Dynamics Optimization Process

Theoretically, the five steps in SD optimization process as presented in Figure 3 (Dangerfield B.C., 2009). Before optimization process begins, we need to identify the important concepts of payoff faction and weight. The objective function can be expressed as a formula using the payoff function. For a calibration optimization, the weight value should always be 1.0 and this value must be assigned to the payoff function. Vensim^{TM} takes the difference between the model variable and the parameters are considered calibration optimization. The optimization process continue searching for the best solution that best fits the simulated AW to the time series data entered as desired AW with the best parameters. The optimization process takes place by maximizing the payoff function. Normally, the value hold by the payoff function is negative and after the process of optimization, the value should be less negative than before. However, the best outcome is when the payoff value after optimization is zero (Bazin, 2011).

Figure-3. System dynamics based optimization modelling process



4.4. Behavioural Change Strategies to Achieve the Desired Average Weight Target

To prevent weight gain, the way is through achieving a specific weight target. Table 1 presents a plausible average weight (AW) target needed by 2020. In order to achieve the desired average weight target of 60 kg in 2020, changes ought to be made in single or combination of sedentary behaviour parameters. Obviously, changes can only take place in the future, so we have chosen 2017 for the policy changes to be rolled out. The three types of scenario experiments were conducted using sensitivity analysis. Details on the type of lifestyles intervention are shown in Table 2. All the intervention strategies required 50% of changes in all dimensions.

Table-1. Changes in average weight values from the past (1996-2015) and into the future (2020)

Variables	1996	2010	2015	2020
Average weight (baseline)	57	61	65	71
Desired average weight				60

Table-2. Type of sedentary behavioural change strategies tested in the model

Type of intervention	Description
Strategy 1 (SB1)	Reducing frequency of sedentary behaviour
Strategy 2 (SB2)	Reducing duration of sedentary behaviour
Strategy 3 (SB3)	Focus on both of frequency and duration of sedentary behaviour

In these experiments, other variables are maintained in the base case model except for chosen parameters (See column 1 in Table 2). Changes in chosen parameters are assumed to commence in 2017. Alterations made in chosen physical activity parameters targeted on reducing sedentary behavior via frequency and duration of sedentary activity. Changes which occur in both energy intake and energy expenditure resulted in changes in energy balance. A greater reduction in energy balance results in more weight reduction. With the achievement in weight target, achievement in the prevalence of obesity target can also be achieved since weight and obesity are interrelated (Kumanyika *et al.*, 2002)

4.5. Model Validation

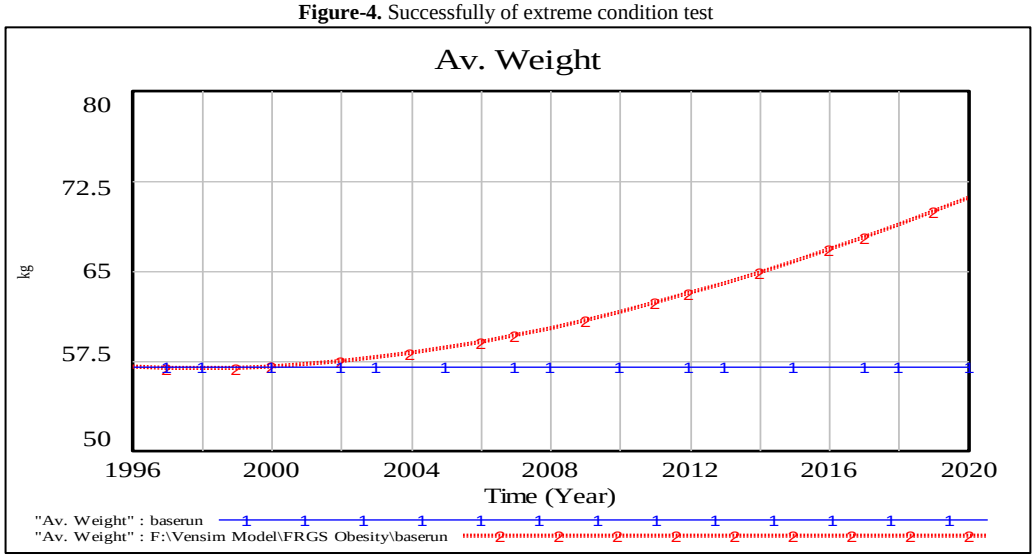
In this research, model was validated with extreme condition test. This test checked whether the model still behaves in a realistic fashion when extreme inputs are given to the model (Sterman, 2002). For testing purpose, extreme value of energy balance zero is set to the model. In theory, if energy intake is equal to energy expenditure, the result is on weight balance and otherwise. It is expected that using extreme condition test, the model should produce the results of maintain in weight given that energy intake is equally to the amount of energy expenditure.

5. Results

5.1. Results of Extreme Condition Test

Result based on the run of extreme condition test shows that the model produced a constant trend of weight value as shown in Figure 4 if we set the energy balance is equal to zero.In this extreme situation, an experiment was conducted by setting the equal of energy intake and energy expenditure value as 2000kcal per day. This situation leads to the achievement of stable trend of weight for the long-term period because all the consume energy was burnt in daily basis.

Figure-4. Successfully of extreme condition test



5.2. Base Run Model

The base run model shows that increase in energy consumption results to the increase in energy balance. With the increase in energy balance, weight is increase and results to the increase in BMI and prevalence of obesity. The trend relations between energy intake, weight, BMI and prevalence of obesity is presented in Figure 5. With an increase in energy intake and frequency and duration of sedentary behavior, this results to the decrease in energy expended through physical activity as shown in Figure 6.

Figure-5. Linkage between the effect of energy intake andbody measurements

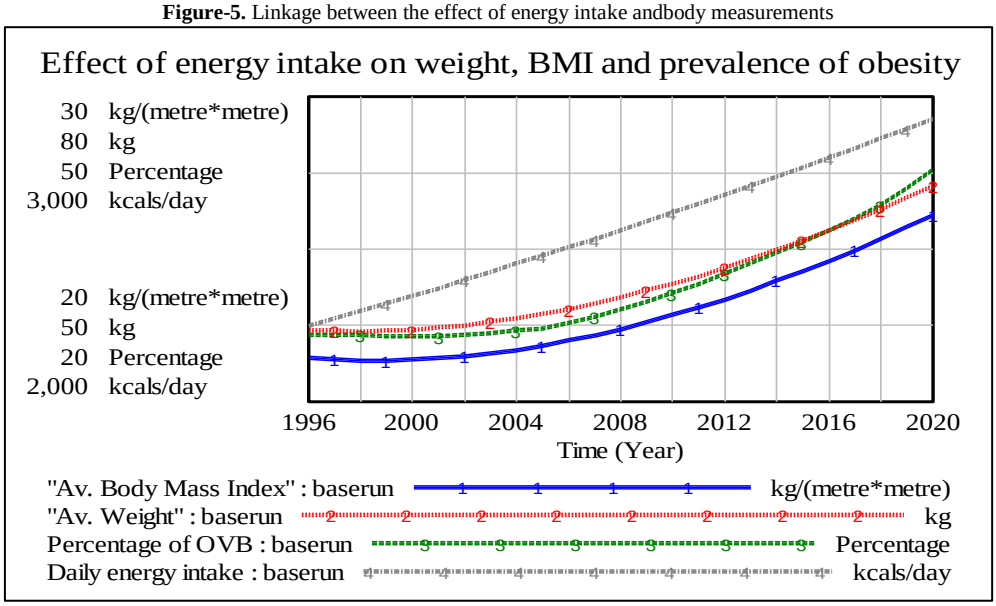
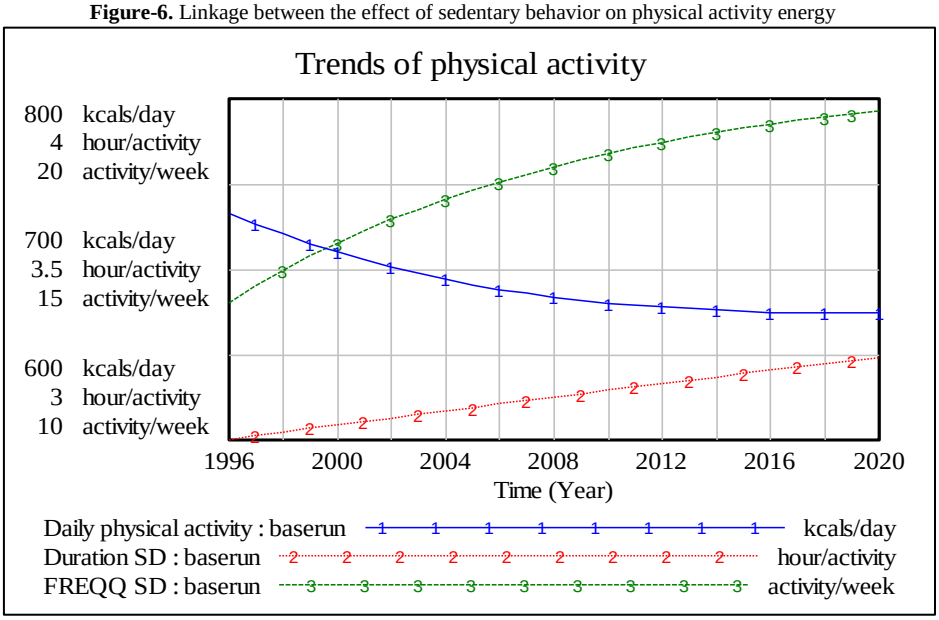


Figure-6. Linkage between the effect of sedentary behavior on physical activity energy



Finding from baserun model shows that sedentary behaviour is one of the causes that results to the less energy expended due to the increase in energy balance. This is due to any activities involving sedentary behavior will not burning energy instead will cause to higher consumption of energy as a result from eating activities normally occur while performing sedentary activity like watching television. Reduce in the number of sedentary behavior cause to the replacement towards active lifestyle that helps to increase burning energy through physical activity energy. For the long term process, this resulted to the weight increment of our population. This study was supported by works from (Coon *et al.*, 2001; French *et al.*, 2001; Robinson *et al.*, 2001; Salmon *et al.*, 2000; Shields and Tremblay, 2008; Vioque *et al.*, 2000) that also shows sedentary behavior including activity at home and in leisure time activity including sleeping and watching television is one of the reason for overweight and obesity that attack our society today.

6. Conclusion and Future Works

In this paper, the problem of obesity related to eating and activity lifestyle is highlighted. The elements of obesity system consists of food intake, energy expenditure and physical measurement have been synthesized in one multifaceted human weight regulation. This paper involves development of SD based optimization model to simulate the effect of changes in sedentary behaviour. Through this study, health decision maker is able to strategize the best

lifestyle activities should be practice in relation to prevent weight gain due to obesity related to many negative impact towards health and psychosocial problems including cost burden to the country.The future work is to present the work from SD optimization model to incorporate the results of changing in both frequency and duration of sedentary behavior that reflects on the achievement of weight target. As this study only focus on the impact of sedentary behavior, this research has opportunity for future improvement by considering the effect on both eating and lifestyle changes in the achievement of the populations of weight target.

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