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System Dynamics Modelling and its Implications for Childhood Obesity Prevention: Evidence from Improving the Consumption of Portion Size and Meal Frequency

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Abstract

The childhood obesity has rapidly increased, though little is known about the impact of frequency of meals and portion size on weight and obesity. The objective of this study is to compare and to determine the effective strategy for obesity prevention by improving the consumption of portion size and meal frequency. This study utilised the secondary data obtained from the Health Survey for England for the child population aged between 2 to 15 years in United Kingdom

This study combines the different strands of knowledge from nutrition, physical activity and body metabolism and synthesizing this knowledge into a system dynamics model which the model offers unique insights into the cause-and-effect relationships among the influencing factors. Findings from the simulation analysis demonstrated that reducing meal frequency is the most effective controlling strategy for obesity prevention. This is asserted by the fact that the highest reduction in average weight (3.14%-4.5%) and average body mass index (3.14%-4.5%) between 2020 and 2030 was observed by improving meal frequency. This paper concludes that system dynamics utilised in this study will be advantageous to guide the food stakeholder to gain insight into the complex of eating behavior and to experiment with various intervention strategies for obesity prevention.

Keywords: Obesity, system dynamics, meal frequency, portion size

1 Introduction

Globally, more than 40 million children around the world under the age of five were found to be overweight in 2010 [1]. The link between obesity and direct health consequences is well acknowledged in literatures. Apart of the disease that children faced related to obesity [2], the impact of obesity can also be seen from a decrease in their self-esteem [3] and lowering of their academic performance [4]. Even though diseases related to obesity in children are perhaps not as serious as for adults, obesity is a part of continuous process where obese children increases the risk of being obese as an adult [2].

In the United Kingdom (UK), the prevalence of overweight and obese children in England has increased since 1995 [5]. In response to the rise in obesity rate, the government has set a target to stop the annual growth in obesity among children under eleven, as part of a broader planned strategy to combat obesity in the child population [6]. Due to the obesity effect on various health and well-being population aspects, all this underlines a need to combat the incidence of obesity.

The factors influencing obesity are varied [1,7]. However, this study only focuses on the eating behaviour, since evidence shows that consuming healthy food has significant results in preventing obesity [7]. From a subsistence perspective, higher income, urbanization, and population growth have increased the demand for food and induced changes in food habits, food purchasing and consumption pattern [8]. One of the impact towards changing in food habits and consumption pattern is the frequent consumption of food away from home. Evidence shows that regular consumption of outside food, for instance fast food restaurants, which is synonymous with bigger portion size, is one of the potential causes of obesity [9, 10]. In relation to food away from home, the impact of meal frequency and portion sizes on weight and obesity mechanism has not been thoroughly assessed. Since obesity is a complex problem [11], hence a best-suited approach to tackle the problem is required.

In this study, system dynamics (SD) simulation modelling is adopted to evaluate the dynamic consequences of two eating control strategies for weight and obesity prevention. The main objective of this study is to highlight the contribution of SD modelling to gain insight into a complex of obesity system. Based on the developed SD model, it can offer the direction of future measurement trend that may cause plausible change under different configurations of eating behaviour action. In conjunction with this, the second objective was to compare the simulated effect of reduction in meals frequency and portion size to determine an effective control strategy for obesity prevention.

The rest of the paper is organized as follows: The compilation of previous studies on the modeling approaches to obesity research was highlighted in the next section. The methodology carried out in this research is described in the following section. Results, discussion and conclusion of the research are presented. Lastly, limitations and recommendations for future works are offered.

2 Brief of literatures on the modelling approaches to obesity studies

There have been many excellent studies conducted using the modeling approach in obesity research. In these studies, methods such as statistics [12,13], and mathematics [14,15] offer a significant contribution to obesity solution especially for trend prediction. Similarly to direct experimental studies, some of quantitative methods mentioned earlier have limitations regarding feedback processes in explaining the existence of relations between influencing factors. Apart of feedback, sometimes these methods need abundant historical data, especially in the case of trend prediction. A final limitation in the focus is often made on specific area of investigation. For example, to investigate the impact of changes in energy intake or physical activity on weight measurement.

Obesity system evolves in non-linear fashion, with delays and feedback processes making contribution [11]. For methodology solution, SD is the best-suited approach since the main advantage of SD is the feedback process. Using SD, the real world complexities like non-linear dynamic, delays and multiple interactions via feedback processes can be studied [16]. In this study, the variation of dynamic influencing factors resulting from nutrition, physical activity and body metabolism are incorporated into SD model by highlighting the interrelations between these various strands of knowledge into one complex human weight regulation system. SD is different from the other conventional approaches, in which numbers of different factors are combined and linked in a single analytical environment model [16].

Furthermore, the current obesity study has a major limitation in obtaining historical data for some important variables, specifically the availability of long-term historical data on energy intake and physical activity. However, it is important to measure and to model for both factors, as they are the foundations of weight influence from behavior context [17,18,19]. Uniquely, SD model manages to handle variables for which there is scant historical data [20]. This can be achieved as long as the modeler has some general idea about the behavior patterns needed for the model, because SD concentrates on the qualitative trends in behavior and de-emphasizes a fit to particular data points [21].

Several obesity studies using the SD approach have been published. The work of Abdel-Hamid [17] used SD approach to model body metabolism and energy regulation. In 2004, Homer *et al.* [18] modeled the impact of caloric imbalance on the changes in body weight and BMI of the adult population in USA. The study of Homer *et al.* [19] was done to model BMI trends of various age categories in the population. However, none of the studies by the researchers focus on the combination of eating and physical activity behavioural changes for childhood population. To fill this gap, this research utilized SD analysis to childhood obesity prevention. Specifically, this paper highlighted the contribution of SD modelling to gain insight into the complex of obesity system, where emphasis is made on the linkages and the cause-and-effect relationships between eating, physical activity and body weight. Changes in eating behaviour of improving in meal frequency and portion size affect on the population weight and BMI.

3 Methodology

In this study, SD modeling was adopted to conceptualize and to model the complex of obesity system. It is a simulation method to understand the changes in behavior of complex problem, with emphasis on the cause-and-effect relations [22]. Both quantitative and qualitative analysis as shown in Figure 1 were used in this modelling process to enhance understanding of obesity system. In this study, qualitative analysis involved with mapping process using causal and loop (CL) diagrams was used. In relation to this study, CL diagram is functioning to capture the hypothesis about the obesity mechanism from feedback consequence. The modelling process continues with quantitative analysis where the stocks and flows of model are developed including the model calibration and model validation procedure [16].

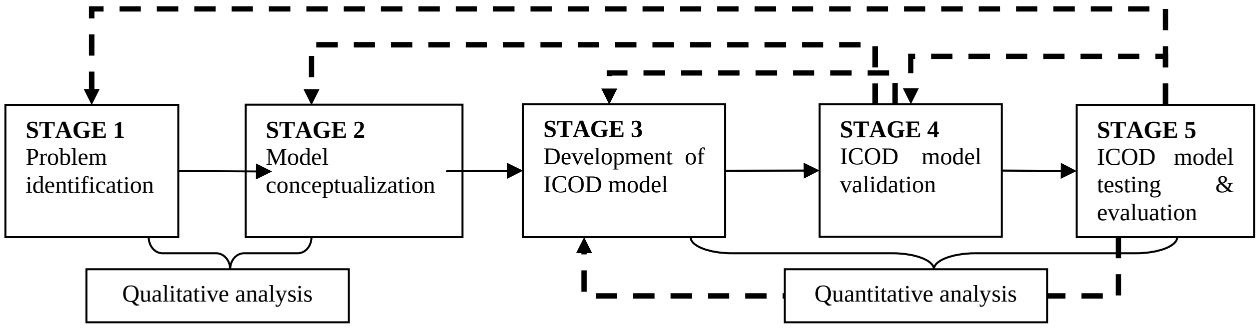

Figure 1**:** The system dynamics of obesity modelling process (adapated from Sterman, 2000)

3.1 Data sources

This study focused on the English child population whose age range from 2 to 15 years as an overall approach to prevent obesity at population level. This study utilised the annual secondary data obtained from statistical survey publications held by the Health Survey for England [5]. The data was also collected from the other published sources. Apart from that, the data was collected from interviews arranged with the experts in physical activity.

3.2 Modelling process

The five general steps in developing the SD of obesity model were given in Figure 1. During the problem identification stage, the obesity issue based on literature is reviewed. In addition, factors that affected obesity, including determination of time horizon, key variables and the boundary of the problem were expanded. Model conceptualization is the development of the framework of the structural assumptions to explain the obesity mechanism from eating and physical activity behaviour. As it is important to ensure that the model is robust enough to answer the purpose of its development, a number of validation tests were conducted. Lastly, the ICOD model ends with a series of 'what-if' analysis to identify the effective eating strategy for weight and obesity solution. In general, the overall modelling process is repeated until the satisfactory results and behaviour that mimic the real problem scenario were successfully duplicated as shown by the dotted line in Figure 1.

3.3 Causal and loop diagram of obesity system

Unlike some of the conventional modelling approaches where consideration is made for separate systems, SD creates a better understanding of the system from a “joined up” or “whole system” thinking approach [21]. Based on these approaches, the model was integrated into the three interrelated sectors of food intake, energy expenditure, and physical measurement into a single SD model (see Figure 2). In this weight system, the dynamics of obesity are portrayed by a change (or combination of few changes) in any part of the system, which then can affect the other party in a feedback process [16].

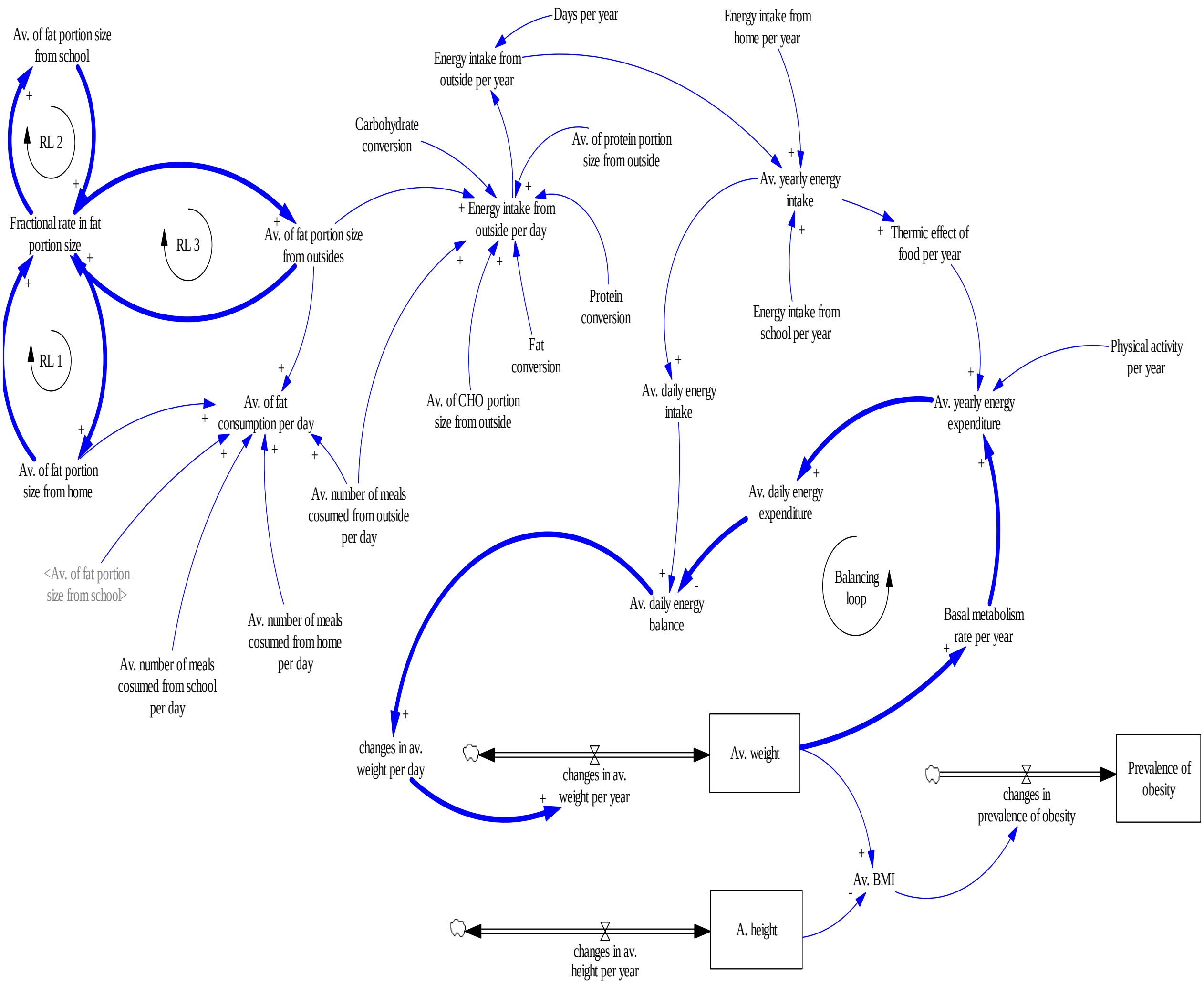

Figure 2: Causal loop diagram of the interaction between eating and physical activities in weight and obesity (Note: RL-Reinforcing Loop)

In order to explain the obesity mechanism, causal loop (CL) diagram was used to connect a set of variables in a linked path. Figure 2 is the overview of CL diagram of human weight regulation system. This diagram provides a unique insight into the dynamics of feedback explanation, taking into account energy intake (EI), energy expenditure (EE), and energy balance (EB). In this study, the interactions between EI, EE and EB and the effect of this energy on AW and ABMI were explored.

There are two types of CL - balancing loop (BL) and reinforcing loop (RL). BL function is to stabilize the system, while RL tends to destabilize. The loop is linked with positive ('+') or 'negative ('-') symbol. The positive sign indicates that the tail variable or constant changes the head variable in the same direction (up or down). In contrast, a negative sign reflects that the head variable is affected in the opposite direction to the change in the tail variable or constant.

3.4 Model formulation

The Vensim^{TM} software version 5.10e was employed in order to model the stocks and flows (SAF) of SD model. SAF emphasizes the physical structure, and this structure generates behaviour that predicts and produces behaviour related to obesity. Stocks (rectangular box) as shown in Figure 2, for example, the stock of weight, are an accumulation of variables over time. A change in a stock can be done through flows (pipe). Since SD captures the changes of variables over time, stocks and flows have to be measured in time units [16].

The model is run between 1970 and 2030 and the time step for simulation run is 0.065. The model is equated for a total aged group of 2 to 15 years by including the six-sub model categories split by gender and three age groups (2-4 years, 5-10 years and 11-15 years).

3.5 Model validation

A series of testing were conducted to validate the ICOD model. The test is conducted to validate both structure and behaviour of the model, as suggested by Sterman [16]. In the structural test, the aim is to ensure the real world structure is correctly transferred into the model. The tests are parameter verification and structure verification. The parameter and structure verification tests are done by comparing the parameter and structure with the review of literatures [17,18]. The aim of both these tests is to ensure that the parameter and structure as adapted from the real structure is correctly transferred into the model.

On the other hand, behaviour reproduction highlights the behaviour pattern generated by the model. This simulated behaviour must replicate the real-world behaviour pattern of AW and ABMI. Figure 3 is showing evidence that the simulate trend is fitting the real average weight of 1995 to 2009 data, collected from Department of Health, UK.

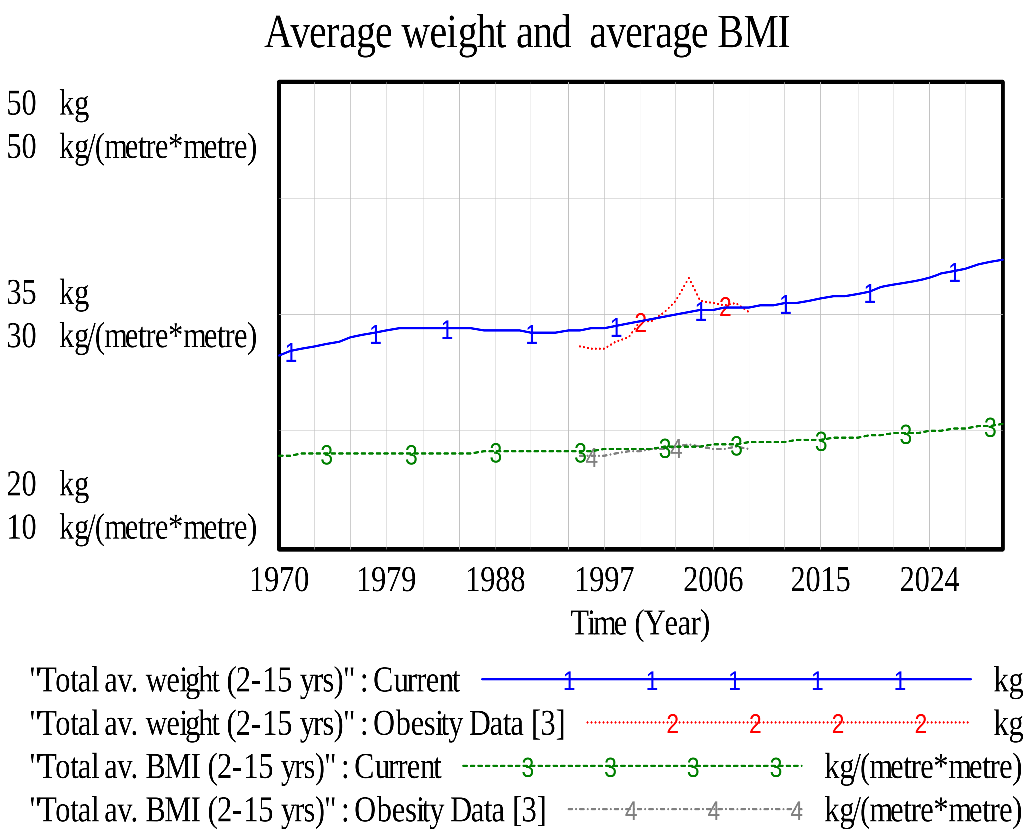

Figure 3: Fitting trends between real data and simulated trends of weight and BMI

4 Results and discussions

The comparative results from the base run and the intervention strategies (called strategy 1 and strategy 2) are presented in Table 1. Base run refers to the analysis without any policy change; meanwhile intervention refers to analysis with policy changes. Along with time, an increased in total AW and ABMI between 1970 and 2030 is observed from the base run analysis. The increase in weight and BMI increment increases in parallel with the portion size and meal frequency consumption between the periods. Our finding is supported by Stamatakis *et al.* [12], who predicted a similar increasing of obesity pattern in the future.

Two sensitivity analysis scenarios were tested with the changes in portion size and meal frequency parameter. The first scenario, known as strategy 1, analyzed the effect of reducing portion size for an outside meal parameter. In this analysis, the parameter was reduced to 50%, and changes were made to all six model categories. Meanwhile, strategy 2 tested the effect of reducing the frequency of meals parameters. Similar to the first analysis, the parameter was reduced to 50% for standardizing measurement. In both analyses, the children maintained their physical activity while controlling their portion size and meal frequency consumption.

The impact of both tests on AW and ABMI measurement trends were analysed and given in Table 1. Findings from the experiments found that almost 5% reduction occurs in AW and ABMI by 2030, via reducing meal frequency compared to portion size strategy, which undergoes nearly 3% reduction.

Table 1: Comparisons in the weight and BMI changes in three specimen years resulting from the two testing strategies

Measurements	Experiment Strategies	Year				
		1970	2020	Percentage of change in 2020 (%)	2030	Percentage of change in 2030 (%)
Average weight (kg)	Base run	32.40	36.69	-	38.56	-
	Strategy 1		35.98	1.90	37.42	2.95
	Strategy 2		35.59	3.00	36.87	4.38
Average BMI (kg/m^2)	Base run	18	19.70	-	20.61	-
	Strategy 1		19.31	1.98	19.99	3.00
	Strategy 2		19.08	3.14	19.68	4.50
Total portion sizes (meals/gram)	Base run	119	156	-	165	-
	Strategy		153	1.92	158	4.20
Meals frequency (meals/year)	Base run	1095	1467	-	1556	-
	Strategy 2		1267	13.6	1305	16.0

Findings from simulation analysis demonstrated that both portion size and meal frequency are connected to weight and BMI. A decrease in children's meal frequencies (about 13%-16%) and portion size (1.9%-4.3%) between 2020 and 2030 was coupled with reduction in AW and ABMI between 2020 and 2030. A similar result was found in the previous studies which supported that portion size and meal frequency are the two important decisions that have an impact on weight and obesity [23,24,25]. Therefore, this result signals an important message to policy makers to promote and advertise healthy eating habits among young citizen. A developed understanding between the effect of meal frequency and portion size on weight and BMI changes may prove helpful for obesity prevention programs. Therefore, it should be considered when developing guidelines to prevent childhood obesity.

Secondly, even though a number of studies supported both factors as determinants of weight and obesity, this relationship has not been rigorously studied. Thus, this study was designed to understand the impact of interaction between food intake and energy expenditure on weight and obesity mechanisms. Importantly, this paper highlighted that the direction of future measurement trend may cause plausible change under different configurations of eating behaviour action, rather than the prediction of the future weight and obesity outcome. The model offers a unique insight by capturing the complex interdependencies among the influencing factors from cause-and-effect explanations. The SD is different from the other conventional approaches, as it can re-create the obesity process at the population level with the feedback processes, where the evidences are properly represented. The model enables decision makers and the publics to understand the dynamics of obesity mechanism, via a quick access of the long-term effect of meal frequency and portion size consumption on the AW and ABMI of child population.

Thirdly, finding from this study discovered that reducing meal frequency is a more effective strategy rather than portion size control in solving weight and obesity problem. Similarly, studies done by Boutella *et al*. [26] and Duffey *et al.* [27] found that reducing meal frequency, especially from food away from home has an impact on weight, BMI and body fatness. However, there are number of study articles on the inverse relationship between meal frequency and changes in weight [23,24]. Increases in the frequency of meal consumption with smaller portion size consumption for each meal, but eaten in regular basis; can increase body metabolism and reduce hunger, thus resulting in weight loss in the long run [28]. The current study defines eating frequency as the number of meals eaten per day with similar portion size for each meal. As the number of meal increases with similar portion size, this might cause weight gain since the amount of portion size is still maintained in a large portion in each meal consumption [29]. Finding from this study provides evidence that reduction of meal frequency is the better strategy to prevent childhood obesity in the UK. This finding adds to the growing literature, which underpins the importance of meal frequency of food away from home sources as among key strategies to alleviate childhood obesity.

5 Conclusions

This paper highlights the linkages and the cause-and-effect relationships in regards to eating behaviour and obesity system. In line with this, the ICOD obesity model was successfully developed with the intention to better understand the impact of meals frequency and portion sizes on a children population's weight and obesity. The development of this obesity model has been conducted through a system dynamics approach that allowed the building of a model structure in which the variables influence one another on the basis of linear and non-linear relations among them. Finding from simulation analysis demonstrated that reducing meal frequency is the most effective strategy compared to controlling portion size. Therefore, this result should be considered when developing guidelines to prevent childhood obesity. This paper concludes that SD is a meaningful approach to guide the food stakeholder to gain insight and to experiment on the dynamic and complex situation of obesity from eating behavior perspective. This study added value to the current literatures in evaluating the possible obesity solutions, by identifying the effective controlling strategy for obesity prevention from a model-based perspective.

6 Limitations and future works

The model was designed to address this issue and to build understanding on the dynamic of obesity in a way that is solidly grounded with the best available science and was useful to non-specialist users, from policy makers to the public. However, this study has a few limitations. The first limitation is the lack of published data on nutrition and PA. The second limitation is this study assumed that whole child population exhibits similar eating behaviour, PA and metabolic process, although heterogeneity in these matters might be observed. To improve upon such limitations, future research can be done by extending the model. One of the interesting areas is the heterogeneity issue, which might be addressed and tested for future research direction.

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