Towards a model-based tool for evaluating population-level interventions against childhood obesity

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Abstract

The prevalence of obesity in the UK is mirroring trends in the USA. There is a need for research to provide public health agencies with advice as to the most effective means of securing behavioural change. The work reported here is in its very early stages. The history of obesity modelling using system dynamics is reviewed. A model of the energy intake and expenditure by a population of children aged 2-15 years is then described. Both of these two influencing factors on the caloric balance are modelled in some detail. A specimen output graph is included before an exposition of the intended use of the model. Mention is made of soft variables and the role of social marketing in effecting behavioural change.

Keywords: childhood obesity; caloric balance; social marketing

Background

In England the prevalence of overweight and obese children has increased since 1995 as illustrated in Figure 1 and Figure 2 (Health Survey for England, 2008). The split percentage of overweight and obese children aged 2 to 15 years in 1995 was 13.1% and 10.9% for boys and 13.1% and 12% for girls increasing 13.8% and 16.8% for boys and 14.1% and 16.1% for girls in 2007. If this trend continues, it is expected that around one quarter of the population aged below 20 could be obese in 2050 as shown in Table 1 (Government Office for Science, 2007).

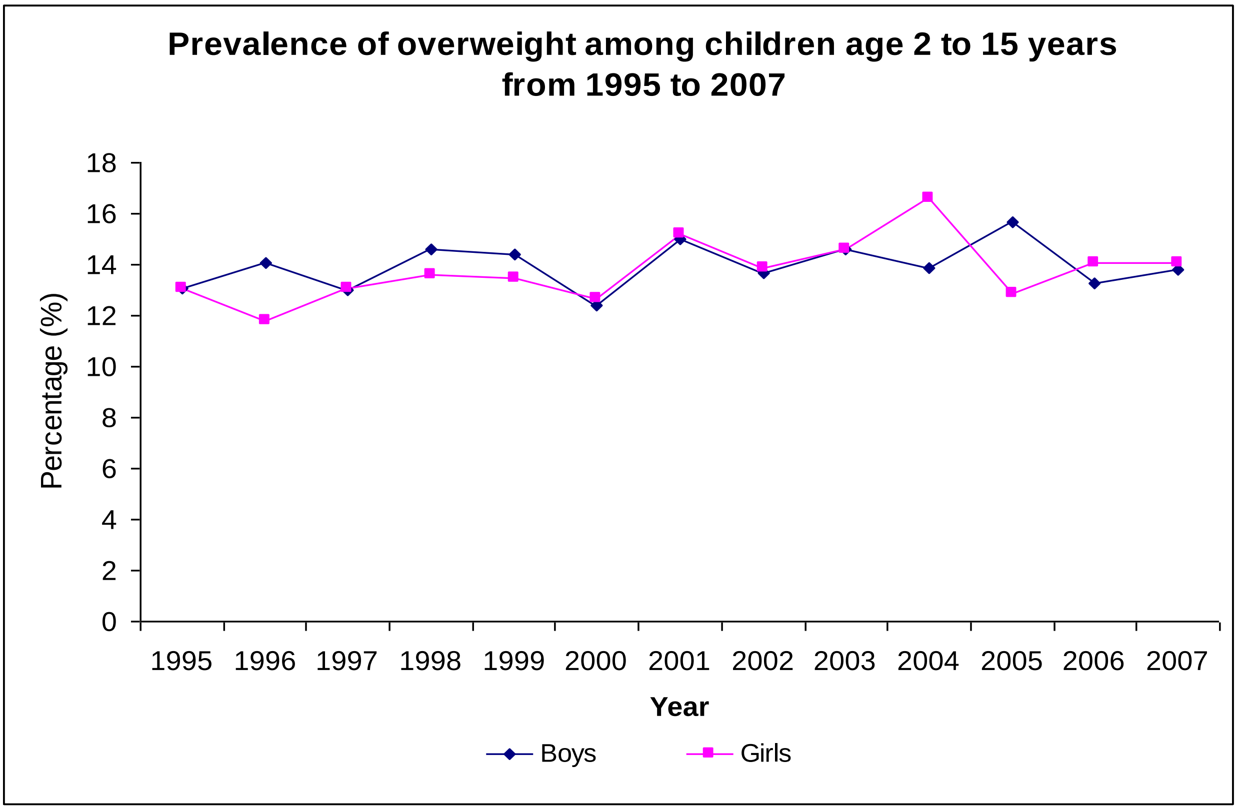

Figure 1: Percentage of children (2-15 yrs) overweight for the years 1995 to 2007 (England)

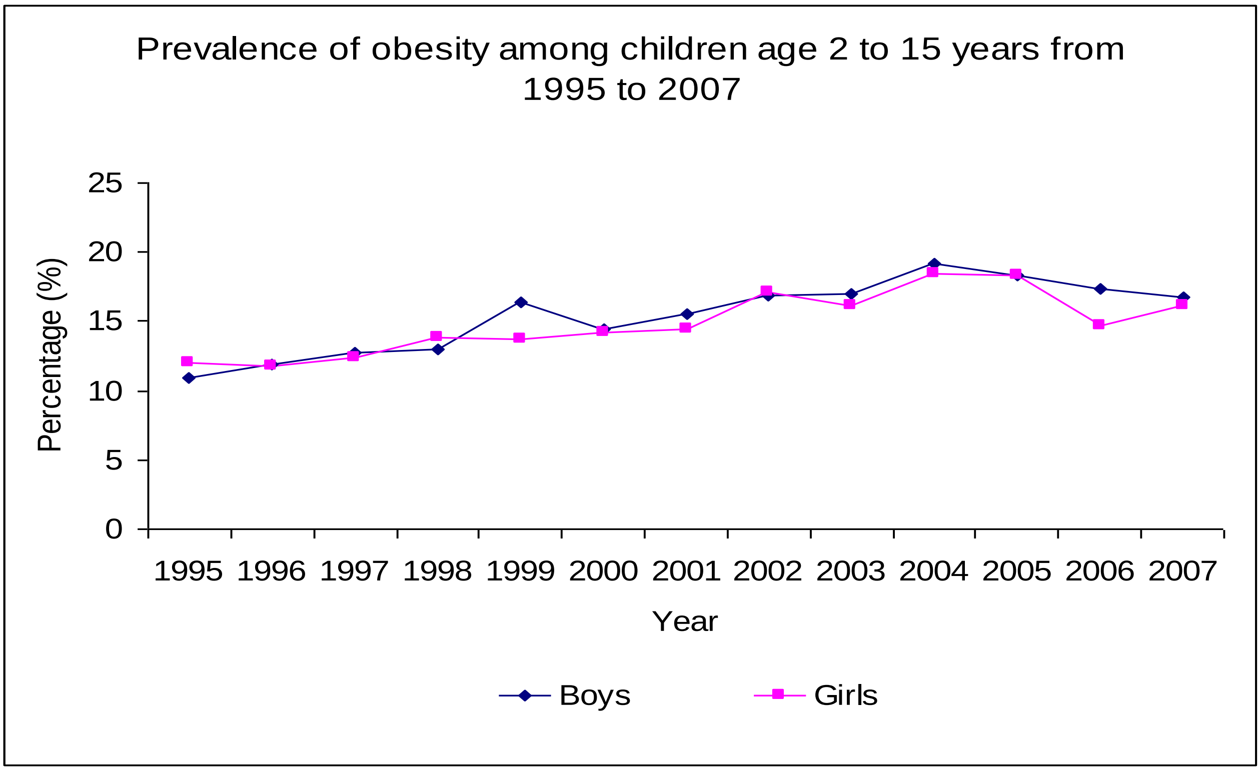

Figure 2: Percentage of obese children (2-15 yrs) for the years 1995 to 2007 (England)

Table 1: Percentage of obese persons in 2007 and 2050 for specific age groups (Source: Government Office for Science, UK)

Population Age	Males (%)		Female (%)	
	2007	2050	2007	2050
1 – 20	7	26	10	26
21 – 30	15	42	3	30
31 – 40	28	65	22	47
41 – 50	26	55	23	52
51 – 60	32	65	27	49
61 – 70	31	64	32	59
71 – 80	28	63	27	44

There are many reasons why an individual might be obese. From a population perspective, it is widely acknowledged by health and other professionals that obesity in the UK population is ultimately driven by genetic, environmental and behavioural factors, as supported in the Foresight report: '… *people's latent biological susceptibility interacting with a changing environment that includes more sedentary lifestyles and increased dietary abundance'* (Government Office for Science, 2007).

Obesity is not a stand-alone issue. Many of the diseases consequent on obesity, which were earlier considered to be adult diseases, are now affecting children as well, including hypertension, type 2 diabetes mellitus, dyslipidemia, cardiovascular problems as well as social and psychological problems (Barlow and Dietz, 1998). In addition to health, obesity also affects wider societal costs such as direct and indirect costs associated with loss of earnings and reduced productivity. For example, the National Health Service in the UK had to spend approximately £1 billion on treating the consequences of obesity in 2002 and the estimated cost could rise to £5.3 billion by 2025 (Health Survey for England, 2008; Government Office for Science, 2007).

The UK government have set a target to halt the year on year rise in obesity among children aged under 11 by 2010 under the perspective of a broader plan to combat obesity in the population as a whole. Unfortunately, there is as yet no proof that these policies have changed the trajectory of obesity growth (Government Office for Science, 2007). Consequently, a new long-term plan has been introduced to replace the previous target. This was announced in September 2007 and aims to reduce the level of obese children to

2000 levels by 2020. This new plan is crucially important. The Prime Minister has stated: ...*'if we do not reverse this, millions of adults and children will inevitably face deteriorating health, a lower quality of life and we face spiralling health and social care costs'* (Cross-Government Obesity Unit, 2008).

Realizing the seriousness of this problem, research is needed to determine the most effective interventions to reverse the current trends in weight, body mass index and prevalence of obesity. To address the challenges of obesity growth, it is suggested that system dynamics can make a significant contribution. Accordingly, the model described in this paper has a twofold aim: to understand the mechanism by which the prevalence of obesity has evolved (a learning purpose) and to explore the potential of various interventions that could reduce the burden of obesity in the child population (an action purpose).

Aims and Objectives

The aim of this study is to understand the long-term consequences for the child population in England (aged 2 to 15 years) of their behaviour in terms of dietary intake and physical activity expenditure and its impact on the changes in their weight and body mass index (BMI). Specifically, the objectives are:

i. To identify factors that influence obesity from a review of the literature
ii. To develop a high-level system map to relate all the factors together
iii. To construct a system dynamics obesity model to explain the trends in average weight and body mass index in the child population of England
iv. To explore interactions between diet and physical activity and their impacts on body weight and body mass index of the child population
v. To determine the most effective interventions underpinning behavioural change designed to tackle aspects of diet and physical activity and which will reverse the current trends in obesity indices

System Dynamics Modelling and Obesity

SD has covered a wide range of complex issues and healthcare is a central and recurring theme (Homer and Hirsch, 2006a). SD has been applied in the healthcare field for almost forty years since the 1970s (Hirsch, 1979; Koelling and Schwandt, 2005). The range of topic areas has included disease epidemiology with studies on HIV/AIDS (Roberts and Dangerfield, 1990; Dangerfield, Fang and Roberts, 2001); dengue fever (Ritchie-Dunham and Mendez Galvan, 1999); cardiovascular (Homer et al, 2008; Homer et al, 2010); Chlamydia (Townshend and Turner, 2000); obesity (Abdel-Hamid, 2002; Homer et al, 2004; Homer et al, 2006); and polio (Thompson and Tebbens, 2008). There are a limited number of researchers tackling obesity-related issues using SD, although significant work has been achieved. Presently, apart from those referenced above, Flatt is the only other researcher we are aware of who is employing an SD-based approach to model obesity.

In 2004b, Homer and colleagues modelled the impact of the caloric imbalance on the changes in body weight and BMI of the adult population in the USA. Obesity is a small part of the model explorations (Homer et al, 2004a; 2004b) because this study mainly focuses on diabetics, assuming that the diagnosed population with diabetes will normally come from the obese category.

Homer et al (2006b) study the whole US population, including children, teenagers and adults aged 0-99 years. The purpose of this study is to understand how the caloric imbalance affects the BMI of various groups in the population. The authors explored the weight transformation from one age group to another using an ageing chain concept. The model contains sixty stocks for ten age groups and gender and three categories of weight (normal, overweight and obese). Changes of flows are derived from equations through the calculation of height, weight, BMI and the amount of energy balance maintained from each of the categories. Outputs include varieties of s-shaped patterns for various BMI categories.

The work of Abdel-Hamid (2002a; 2002b) concerns an SD approach to metabolism and energy regulation. The work assesses the factors of dietary intake and exercise and how these components interact to determine adult body weight and body composition. Specifically, this study has two main objectives: it examines, by comparison, how dietary components (fat, carbohydrate and protein) and exercise intensity level (low, medium, high) impact on the amount and composition of weight loss. Interventions, including the adjustment of dietary components and the level of exercise on changes in body composition and body fat percentage, are explored.

Interestingly, Abdel-Hamid recently (2009) published a book specialising on obesity by applying systems thinking concepts to understanding the development of obesity and an individual's weight management practices. This book focuses on three categories of readers: (i) *individuals* - giving them information to understand and to manage their bodies, (ii) *parents* - to provide them with knowledge about the long-term risk of their children's behaviour concentrating on diet and physical activity. Changes in weight happen quite slowly and obesity is a result from the accumulation of excess weight over a long period of time. There is a third category of reader (iii) *public policy makers* - to provide them with an abundance of knowledge (e.g. nutritional guidelines) in order to help them in planning strategies to reduce the obesity burden in the population.

Flatt (2004) has also applied SD modelling to explore obesity conditions. In contrast to Homer and Abdel-Hamid, he is concerned with looking at the situation from a dietary intake perspective. He investigates the impact of interactions between the metabolism of carbohydrates and protein and the role these play in the regulation of body weight and body composition.

All the SD-based obesity studies discussed above are summarised in Table A1 in the appendix.

Differences between this study and previous SD obesity studies

What make this study different from other SD obesity studies? Firstly, this study is focussed upon English children (aged 2 to 15 years) compared to Abdel-Hamid (2002a; 2002b) and Flatt (2004) whose focus is on individual adults. Homer et al (2006) concentrate on the entire US population (0-99 years).

Secondly, this study models the child population average weight and body mass index. Contrast this with Homer et al (2006) who model obesity by examining weight changes as segments of the population move from one to the same or a different body mass index category. Abdel-Hamid (2002) models obesity from the perspective of the amount and direction of weight loss.

Thirdly, this study will ultimately focus upon the prevention of childhood obesity whereas Abdel-Hamid (2002a; 2002b; 2009) examines treatment. Homer et al (2004a; 2004b) also focus on prevention. It is important to differentiate between treatment and prevention because an emphasis on prevention is more effective. Body weight is difficult and costly to lose when it is already developed. Preventing obesity needs behavioural changes from the environment as well as organisations, communities, families and the individual (Government Office for Science, 2007).

Finally, this study embraces the dietary intake behaviour of the child population, measuring food and energy consumption from both food *composition* (protein, carbohydrate and fat) and *sources of foods* (home, school or outside). No previous research has approached the problem from this angle – re-creating the actual energy intake and energy expenditure habits of a changing population.

Structure of the model

Our model is represented by a stock and flow diagram (figure 3). In a gender-separated model the age groups are split into 2-4 years; 5-10 years; and 11-15 years. This mimics nursery, primary and secondary education in England. The gender and age groups are handled by means of the array facility in Vensim. There are two reasons for this disaggregation in the model. Firstly, each category has its own needs for energy and body metabolism (e.g. females have more fat than do males) and they exhibit different behaviour patterns (in terms of dietary intake and physical activity) (FAO/WHO/UNU, 2004; Butte et al, 2007). Secondly, the prevalence of obesity trends for each group and gender are different. The purpose of this study needs emphasising again: it is to provide policy makers with clear information. Presenting the trends by aggregating them does not provide complete information for further interventions (Health Survey for England, 2008).

This model embraces both the energy intake and energy expenditure components and these features are modelled in some detail. Food is assumed to be consumed at home, in school or on outside premises such as cafes and (increasingly in the UK for this population) in fast-food restaurants and take-aways. The three types of energy derived from food consumption (fat, carbohydrate and protein expressed as kcals per time unit) are computed by considering the composition of the typical meal which is assumed to vary with the location of consumption (home, school or outside). The formulation also takes into account changing portion sizes (grams per meal) and the frequency of consumption (meals per year).

Energy expenditure (kcals per time unit) includes the basal metabolic rate, energy required for childhood growth and the thermic effect of food consumption itself, as well the more obvious means of expending energy through four categories of activity: sedentary, light, moderate, and vigorous. This model investigates each component of activity because it provides different sources of intervention. It is supported by the research literature which suggests sedentary activity has increased over time as active activity is replaced by more sedentary activity. In the age of the internet there is a prima facie case to explore: that of a more sedentary lifestyle for children and young people. Instead of the type of activity, we include factors such as duration, frequency and intensity that all contribute to energy expenditure arising from physical activity.

The concept of energy balance is introduced in the model to represent the quantity of energy surplus or deficit based on the difference between energy intake and energy expenditure. Weight gain occurs due to increased energy intake and reduced energy expenditure or both actions simultaneously. Weight loss is achieved by the reverse action and weight is stable if energy intake is equal to energy expenditure (Egger and Swinburn, 1997). In this situation energy balance has a zero value.

We have taken 1970 as the starting year for the model runs based upon an assumption that energy balance was broadly neutral at that time; childhood obesity was almost never heard of then. The prevalence of overweight and obesity started to increase (slowly) in the 1980s and more dramatically in the 1990s. The model is calibrated in years and so changes in daily energy balance and weight variability are smoothed out to result in more stable average weight changes in a year. However, because eating and performing physical activity is a daily process, this model additionally computes energy intake and energy expenditure in daily units (kcal/day) to aid understanding and to reflect common health nomenclature.

The model also investigates the impact of body mass index (BMI) on the prevalence of obesity. All model variables and parameter values are derived from empirical studies reported in the literature. Table 2 lists the key variables and parameters used in this study. As this model is structured to examine weight changes in the child population, all the variables are average values (e.g. units per person).

Table 2: Selected key variables and constant values used in the model (NB. FM= Fat Mass; FFM= Fat Free Mass)

Model Components	Name	Type	Units	Equations / values	Data Sources/ Literature
Energy Intake	Fat conversion	Constant	kcal/gram	9	Abdel-Hamid (2002a, 2002b); Homer et al (2004b).
	Carbohydrate conversion	Constant	kcal/gram	3.5	
	Protein conversion	Constant	kcal/gram	4	
	Total energy intake	Flow/auxiliary	kcal/day & kcal/year	Fat conversion x (fat consumption) + Protein conversion x (protein consumption)+ Carbohydrate conversion x (carbohydrate consumption)	
Energy Expenditure	Thermic Effect of Food (TEF)	Auxiliary	kcal/day & kcal/year	energy intake x 10%	Abdel-Hamid (2002a, 2002b); Homer et al (2004b) Butte et al (2007).
	Basal metabolism rate (BMR)	Auxiliary	kcal/day & kcal/year	(basal energy expenditure FM *body fat)+(basal energy expenditure FFM*non-body fat)	
	Physical activity	Stock	kcal/day & kcal/year	active activity-inactive activity	Abdel-Hamid (2002a, 2002); Homer et al (2004b).
	Total energy expenditure	Flow/auxiliary	kcal/day & kcal/year	BMR + TEF + Physical activity	
Physical Measurement	Average Weight	Stock	Kg	Initial value	Health Survey of England (Data from 1995 to 2007).
	Average Height	Stock	metre	Initial value	
	Average BMI	Auxiliary	kg/metre squared	Average Weight/(Average Height x Average Height)	
Obesity Fraction	Prevalence of Obesity	Stock	percentage	Diagnosed-Treated	Health Survey of England (Data from 1995 to 2007).

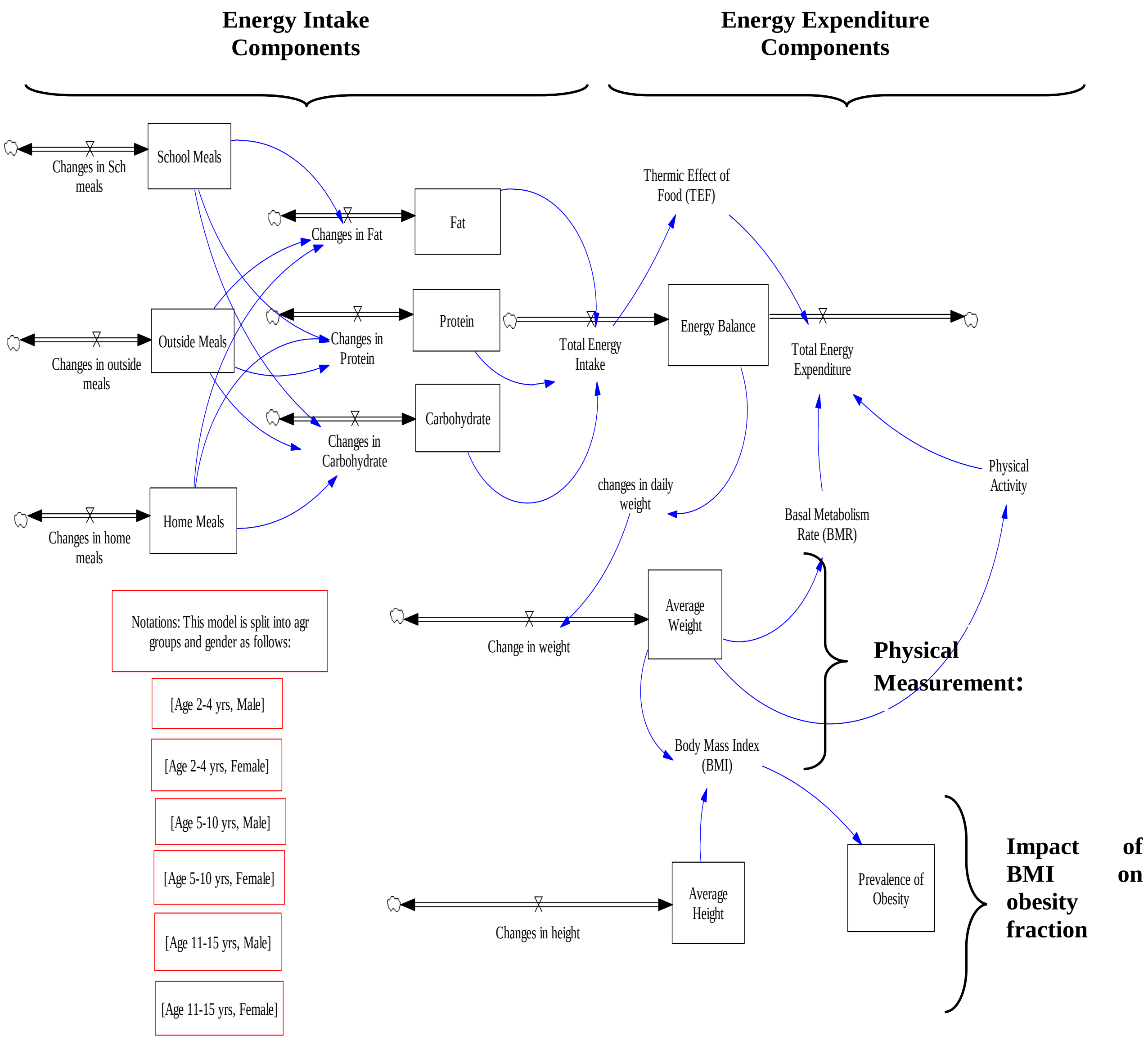

Figure 3: Stock and Flow Diagram: Dynamic Hypothesis for Obesity Centred on Energy Balance

The model runs from 1970 to 2020. The rationale for this is to allow for a comparison with past data and to secure a baseline when childhood obesity was virtually unknown. Some reported data is available for certain of the model variables, but it does not span the entirety of the past history covered by the simulation. The projections to 2020 chime with a target date for government policy aimed at reversing current trends (Cross-Government Obesity Unit, 2008): the stated policy is to bring childhood obesity prevalence back to 2000 figures by 2020. We have conducted an experiment as part of our validation tests by running the model until 2050. The outputs for BMI for the same example show similar increasing trends as does running it until 2020, as shown in Figure 6.

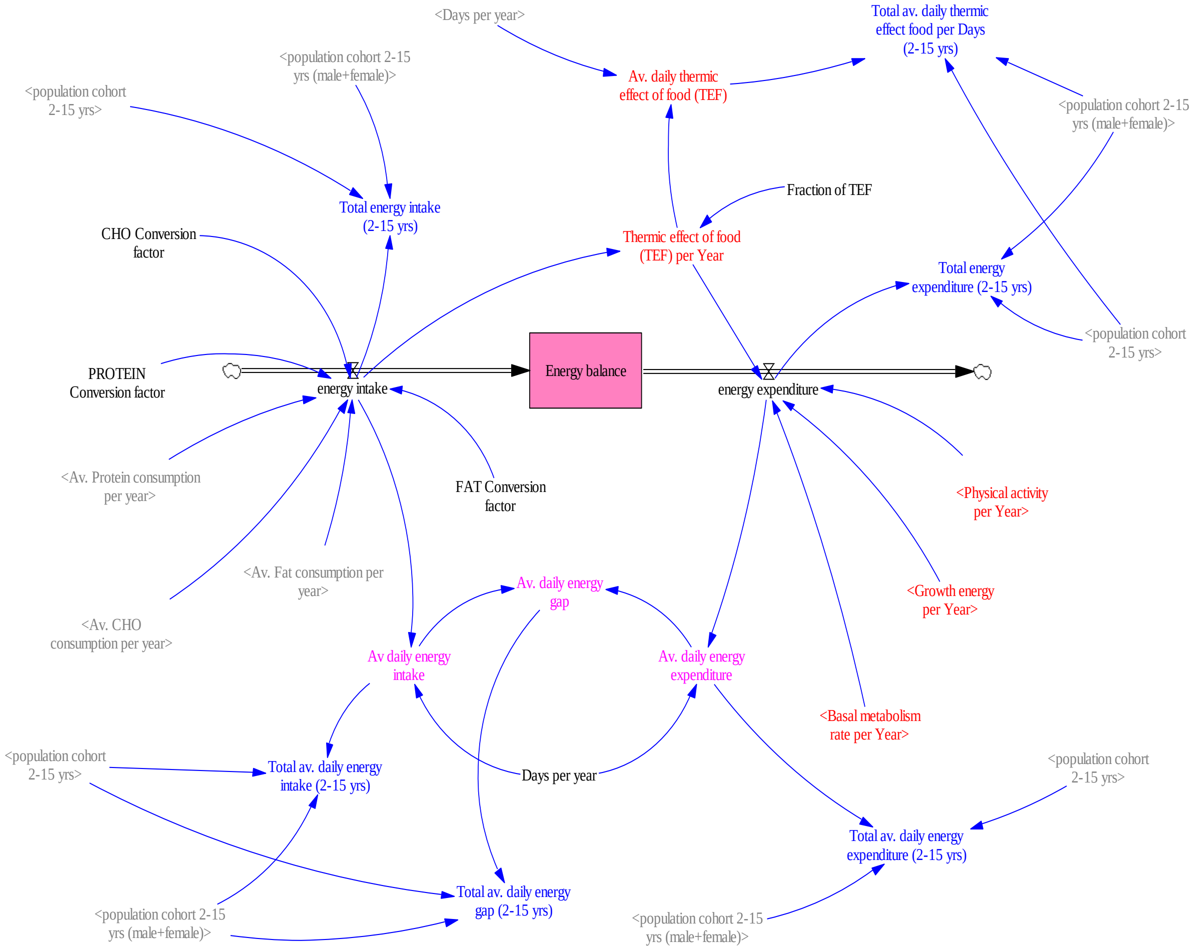

Figure 4: Aggregate of energy intake and energy expenditure

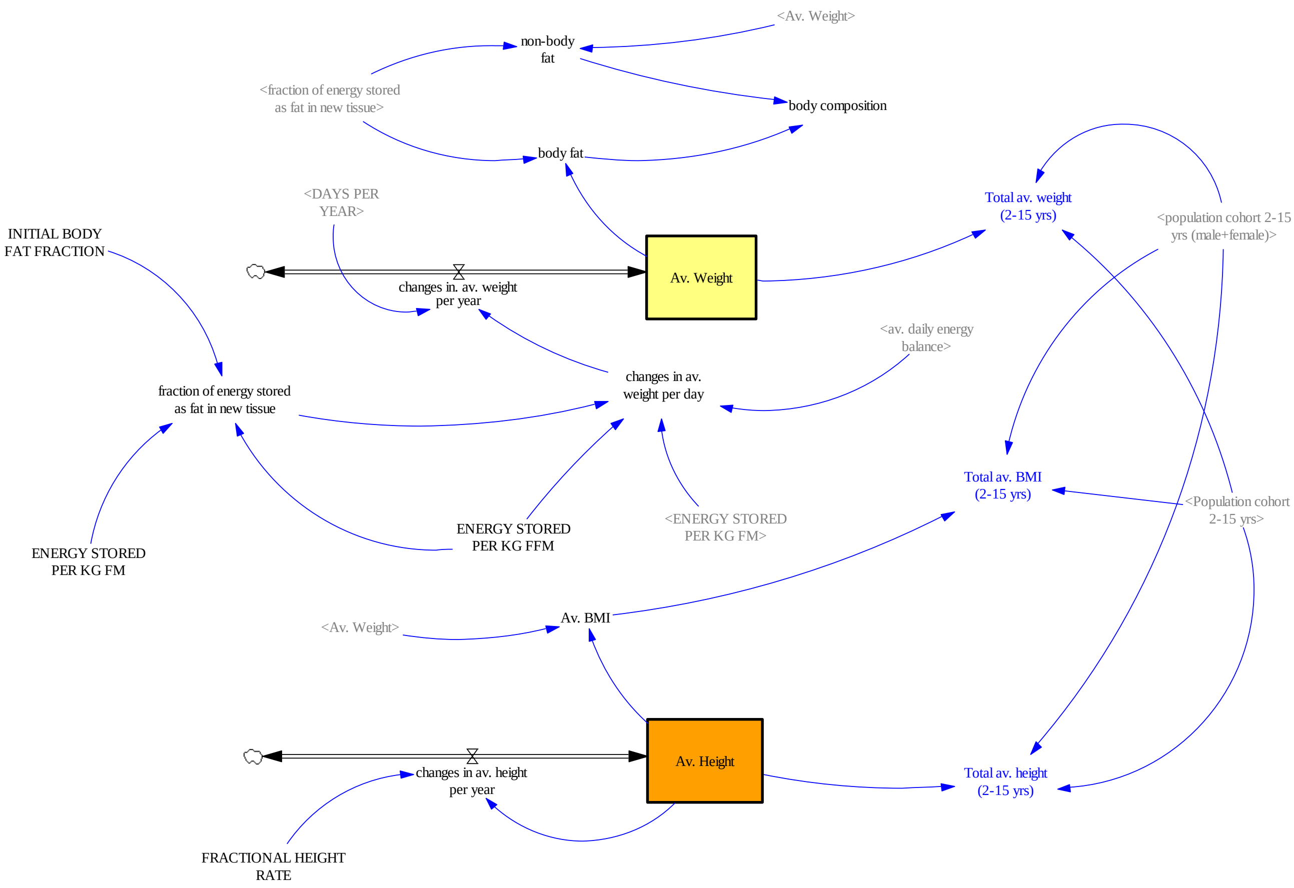

Figure 5: Structure to model weight, height and BMI

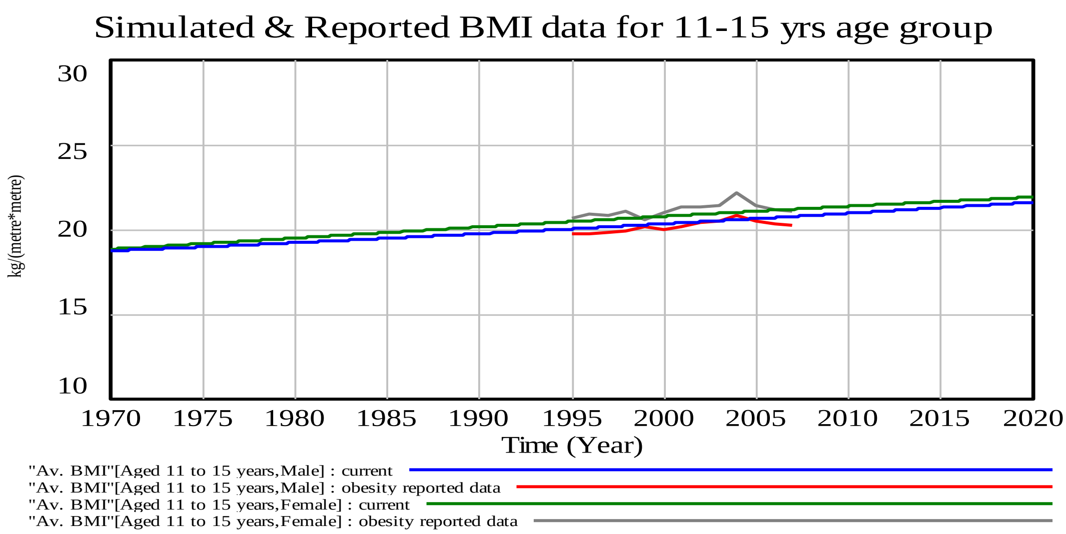

Figure 6: A specimen of model output – simulated and reported BMI (11-15 yr)

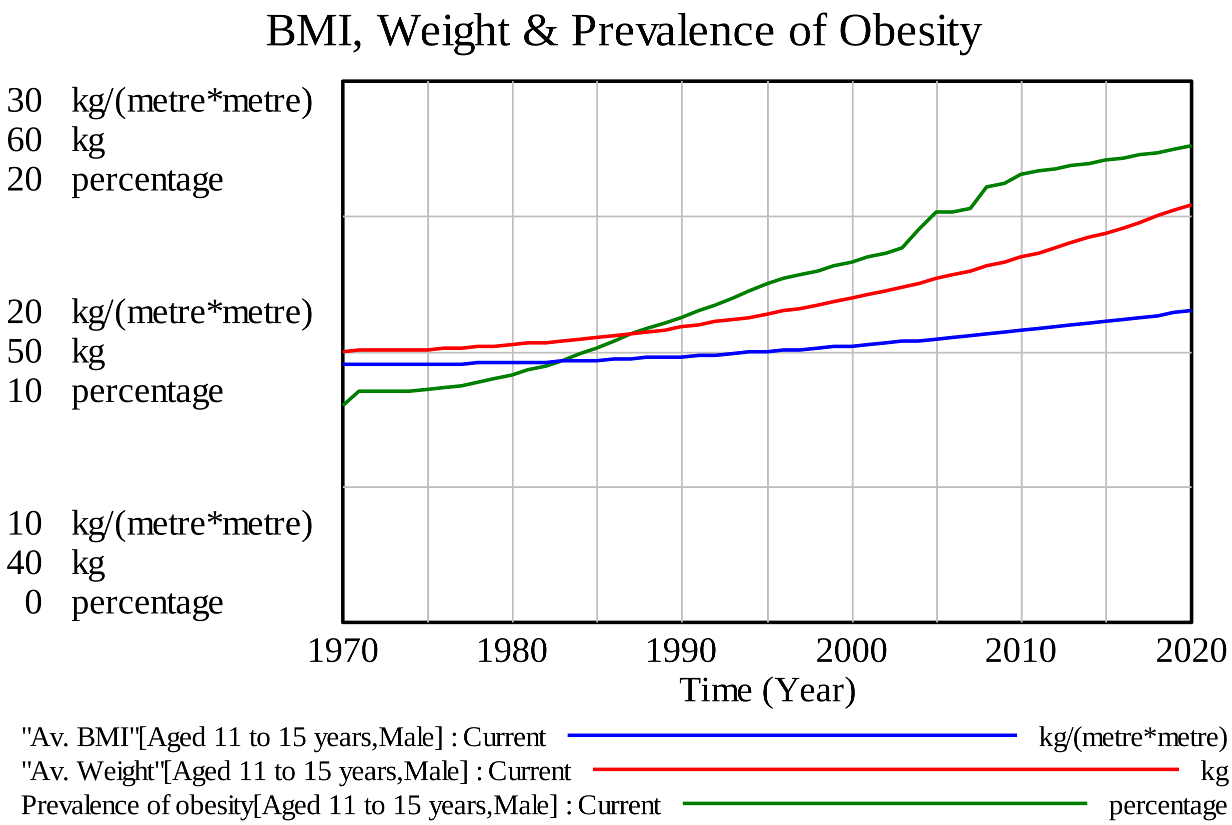

Figure 7: Changes in weight, BMI and prevalence of obesity from 1970 to 2020

One of the model views is reproduced in figure 4, together with specimen output graph of the BMI projection (figure 6) as well as a much shorter series of reported historical data. Meanwhile, outputs graph for weight, BMI and prevalence of obesity (figure 7) for the 11-15 years age group is drives form the model structure in Figure 5. Figure 4 is one of (currently) 16 views in the model, but it is a central sector covering the summation of energy intake and expenditure. The latest version of the model consists of 250 equations and mappings. It is a work in progress and has not yet been exposed to public health specialists and, as such, the exactitude of the parameter values is open to debate.

Policy Implications

Following the usual validation tests which develop confidence in the model, such as dimensional analysis, structure and parameter assessment (Sterman, 2000; Forrester and Senge, 1980), we intend to perform policy testing covering energy intake, energy expenditure and combinations from each component. This will be carried out by changing the parameter values we have some control over and then determining the best output targets to reduce weight, BMI and prevalence of obesity. Table 3 lists selected of policy testing from energy intake and energy expenditure that are planning to be experiment in the next future works under *Policy Design and Evaluation* stage (Sterman, 2000).

Table 3: Selected policy testing from energy intake and energy expenditure components

Components of Policy Testing	Testing Type
1. Energy Intake (EI)	Decrease in fat consumption (DFC)
2. Energy Expenditure (EE)	Increase frequency of physical activity (IFPA)
	Increase duration of physical activity (IDPA)
	Increase intensity of physical activity (IIPA)
3. Combination (EI & EE)	DFC & IFPA
	DFC & IDPA
	DFC & IIPA

Intended Future Work

The purpose of the model is to provide a tool which can be employed to ascertain the effectiveness (including cost-effectiveness) of a range of population-level measures designed to invoke behavioural change in either activity habits or eating habits or both. How can public health agencies achieve 'more bang for the buck'?

Soft variables can be introduced into the model. Softer variables stem from work surrounding interventions and are likely to be based on the various applications of social marketing. This has been defined as the use of marketing tools and techniques to bring about a societal benefit (e.g. 'Social Marketing-Based Strategy for Obesity Interventions': Report prepared for the South-West Public Health Observatory, Tapp, Eagle & Spotswood, 2008). We believe that there is considerable scope for developing the underlying theory and application of theory in this field and subject area. Specifically, we are planning to apply a Theory of Planned Behaviour in this model to understand how our population make decision on eating and physical activity event. We attempts to look at attribute of *intention*, *social norms*, *attitude* and *perceived behaviour control* that influence on this decision (Ajzen, 1991). In this work also, we aim to acquire a greater understanding of retailer influences and the ensuing food advertising, product placement and general promotion for unhealthy products.

Estimated costs of various interventions will be included so as to provide evidence on cost-effectiveness. Some lower cost action may result in securing only a temporary benefit, whilst a subtle, more expensive and longer-term strategy may reveal a beneficial change in behaviour which is sustainable.

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APPENDIX

Table A1: Summary and scope of the four main system dynamics obesity studies

Description	Abdel-Hamid	Homer and colleagues			Flatt
Type of Publication (Conference or Journal)	System Dynamics Review/ Journal of the American College of Sports Medicine	22nd International conference of the System Dynamics Society, Oxford, England	24th International Conference of the System Dynamics Society; Nijmegen, The Netherlands	-	Obesity Research
Title of the Paper	Modelling the dynamics of human energy regulation and its implications for obesity treatment/Exercise and Diet in Obesity Treatment: An Integrative System Dynamics Perspective	The CDC's Diabetes Systems Modelling project: Developing a New Tool for Chronic Disease Prevention and Control	Obesity Population Dynamics: Exploring Historical Growth and Plausible Futures in the US	Diabetes System Model Reference Guidance	Carbohydrate-Fat Interactions and Obesity Examined by a Two-Compartment Computer Model
Year of Publication	2002 & 2002	2004a	2006	2004b	2004
Country Applied	United States	United States	United States	United States	United States
Sample addressed	Adults	Adults	Overall population	Adults	Adults
Objectives	To study and gain insight into the impacts of exercise and diet on weight loss	To model the impact of the population who diagnosed with diabetics effect the obesity population	To understand the changing trends in weight categories (normal weight, overweight, and obesity) for all ages of the US population	• To model an average of adult body weight and Body Mass Index (BMI) • To design and evaluate the intervention strategies related to diabetes and obesity	To examine the interactions between carbohydrate and fat metabolism on the body weight regulation.
Model Duration	0 to 2000 hours	1980 to 2050	1970 to 2005	1980 to 2000	0 to 3000 hours (125 days)
Outputs	*First Objective:* To compare the impacts of diet and exercise treatment on the amount and composition of weight loss *Second Objective:* The impacts of different exercise intensity levels (low, medium & high) on the changes in body weight	▪ Obesity prevalence trends (obese % of adults)	Changes in trend of overweight & obesity (1970 to 2005) which reflect the carrying over of BMI status from one stage of life to the next over the whole population (10 age groups x 2 genders x 3 BMI	▪ Changes in trend of an average of BMI for the adult population ▪ Changes in trend of an average of caloric intake and physical activity	Changes in mean glycogen levels when subjects are given different percentages of fat in food.

	and % of body fat		categories)		
Interventions	▪ Adjustment of the diet components (fat, CHO and protein) ▪ Adjustments of the physical activity level (low, moderate and high)	▪ Adjustment of caloric intake by decreased of mean energy intake for 2% (2416 kcal per person per day) and 3%. (2391 kcal per person per day) ▪ The basic mean caloric intake adults population is 2465 kcal per person per day	▪ Adjustment of the caloric imbalance for the various categories of age group	▪ Adjustment of caloric intake	• Adjustment of the fat and carbohydrate from food consumption
Scope of the research	▪ Targeting adults individually ▪ Focus on treatment	▪ Targeting the adult population ▪ Focus on prevention	▪ Targeting the overall population (0-99 years) ▪ Focus on prevention	▪ Targeting the adult population ▪ Focus on prevention	• Targeting adults individually • Focus on prevention