

The Role of Behaviour Change in Eating and Physical Activity in the Battle against Childhood Obesity

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Obesity results from many influences including genetic and environmental. But eating and physical activity are the two fundamental factors which influence obesity development. This work investigates how food consumption choices and the extent of physical activity have an influence on weight, BMI and the prevalence of obesity in a population of children aged 2-15 years. Around forty years ago, the weight profile of the child (or adult) population was not particularly abnormal. But with increases in energy-dense food consumption and reductions in physical activity, weight, BMI and the prevalence of obesity has increased dramatically, especially since the 1990's. Results from our model can explain these trends. If no interventions are taken to counteract them then these markers will continue to increase in the future with consequential health effects as the children become adults. In an effort to uncover the most effective interventions, this study highlights the role that a system dynamics model can play to help manage the problem in childhood, particularly through considering behavioural changes. Optimisation experiments are conducted to determine whether interventions on the energy intake or energy expenditure sides are likely to be most effective. In anticipated developments of this research it is suggested that the Theory of Planned Behaviour could be used as a framework to identify the motivational factors that influence children in their eating and physical activity habits.

Keywords- System dynamics; childhood obesity; physical activity; food intake; average weight; body mass index; obesity prevalence; energy balance.

1 INTRODUCTION

The prevalence of obesity among children is increasing, especially in developed countries like the USA and the UK. In England, the prevalence of overweight and obese children has increased since 1995. The split percentage of obese children aged 2 to 15 years in 1995 was 11.1% for boys and 12.2% for girls respectively, increasing to 16.1% for boys and 15.3% for girls in 2009 (NHS, 2011). If this trend continues, it is expected that around one quarter of the population aged below 20 could be obese in 2050 (McPherson et al. 2007).

Obesity is a complex issue because of two reasons: firstly, many potential factors contribute to the development of obesity. For example, we can cite environmental factors (e.g. overlarge food portions in fast food restaurants, the lack of neighbourhood sidewalks and food advertising), genetic and family history factors, eating habits (e.g. higher consumption of fat and frequent consumption of energy-dense take-away food) and the adoption of inactive lifestyles (Department of Health, 2008; Dehghan et al. 2005; Kumanyika et al. 2002). Secondly, obesity evolves in a non-linear fashion, with time delays and feedback processes making a contribution (Levy et al. 2010).

Even though diseases related to obesity in children are perhaps not as serious as those in adults, obesity is part of a continuous process. Obesity in childhood underpins the development of obesity in adults (Choudhary et al. 2007). Obese children have the strong possibility of becoming obese adults when they are grown up (Speiser et al. 2005; Guo et al. 2002). Being an obese child not only impacts on their health but also on their social life. Even more importantly, obese children often exhibit low self-esteem and depression resulting from their physical condition. They are stigmatised by society and often get bullied by their school peers. These phenomena indirectly impact on their educational performance and their ability to learn (Datar et al. 2004; Byrd et al. 2007).

An urgent solution is needed to prevent obesity continuing to increase in the future. There are many negative impacts resulting from obesity such the costs incurred in the light of the health consequences (NHS, 2011). Many of the previous studies of obesity have been of a qualitative nature and were undertaken in a natural setting context. These type of studies allow researchers to have direct observations of their subjects. Unfortunately, they are costly and time consuming. Studies of a direct experimental nature, which aim to assess the impact on weight and BMI, have not provided sufficient evidence of any significant immediate results and this suggests that more time may be required in order to see any impact (Caballero et al. 2003).

Therefore, because of the complexities inherent in the obesity problem and with a combination of time and cost constraints, it is necessary to research the utility that may be offered through modelling methodologies. Simulation is one modelling method which is useful in helping to evaluate large and complex problems (Ingalls et al. 2008; Taylor and Lane, 1998). By using simulation models an evaluation of the effectiveness of a variety of policies can be made. The randomized controlled trial settings found in most qualitative studies allow of only a limited number of policy interventions to be considered as compared to settings where computer simulation is employed (Levy et al. 2010). System dynamics modelling is a tool that provides a framework to understand this complex health-related problem and is very useful for experiments that involve non-linear effects and feedback processes (Sterman, 2000).

An initial purpose of this study is to develop a system dynamics model that can be employed to quantify the relation between the energy balance, created by differences between energy intake and energy expenditure, and how changes in this affect average weight in the child population, together with its impact on BMI and the prevalence of obesity in the relevant age groups. Section 2 presents the model structure used to explain the overall obesity process taking into consideration both food intake and physical activity behaviour. The discussion continues with validation tests performed on the model in Section 3. To promote understanding of the ways in which changes in the energy balance impact on weight, BMI and prevalence of obesity, Section 4 reports a sample of output runs from the base case model. Our modelling work is driven by a most important objective: to assess policy interventions that provide workable solutions to the problem. Interventions in this domain refer to population level modifications effected through changes in eating and physical activity behaviour. Section 5 describes the results from two broad illustrative interventions simulated with our model. Related to one of the model objectives in identifying the most effective obesity prevention activities, Section 6 compares the results from optimisation experiments to determine whether changes in eating or physical activity represent the most effective approach to reverse current trends in average weight, BMI and prevalence of obesity. Section 7 summarises the entire paper. Lastly, future work to be undertaken is reported in Section 8.

2 MODEL STRUCTURE

This research is based on the common view that obesity in the UK (as elsewhere) occurs due to changes in eating and physical activity associated with a modern lifestyle (WHO, 2011; Butland et al. 2007; Kumanyika et al. 2002; Crawford and Ball, 2002). From an eating perspective, an increase in energy intake is primarily driven by an increase in the average number of meals (eating

episodes), larger portion sizes and an increase in the consumption of fat associated with meals taken outside of the home and particularly in fast-food restaurants (Young and Nestle, 2002; Young and Nestle, 2007; Butte, 2000; Jéquier, 2001; Bowman and Vinyard, 2004). A marked reduction in physical activity energy expenditure is related to the frequency, duration and intensity of physical activity being replaced by sedentary behaviour (Kumanyika et al. 2002; National Obesity Observatory, 2010; Office for National Statistics, 2011). A description of the conditions that drive obesity are presented from a modelling perspective using the stock and flow diagrams shown in figures 1-4.

As regards eating behaviour, the greater the portion size and number of meals taken results in a larger consumption of total fat whereas the opposite condition applies for a lower consumption (note the double-headed arrows on the flows in figure 1). The energy intake from outside meals, associated with higher fat, carbohydrate and protein portion sizes, and the increasing number of meals eaten outside the home results in a higher proportion of total energy intake being obtained from this source. This process is reflected in figure 3 and by the + signs in figure 2. Turning to the physical activity (PA) aspect, the higher the intensity, frequency and duration of light, moderate and vigorous activity, the higher the PA energy expended. Conversely, if the frequency, intensity and duration of sedentary behaviour were to increase, then PA energy expenditure decreases. This process is illustrated by the + signs in figure 4.

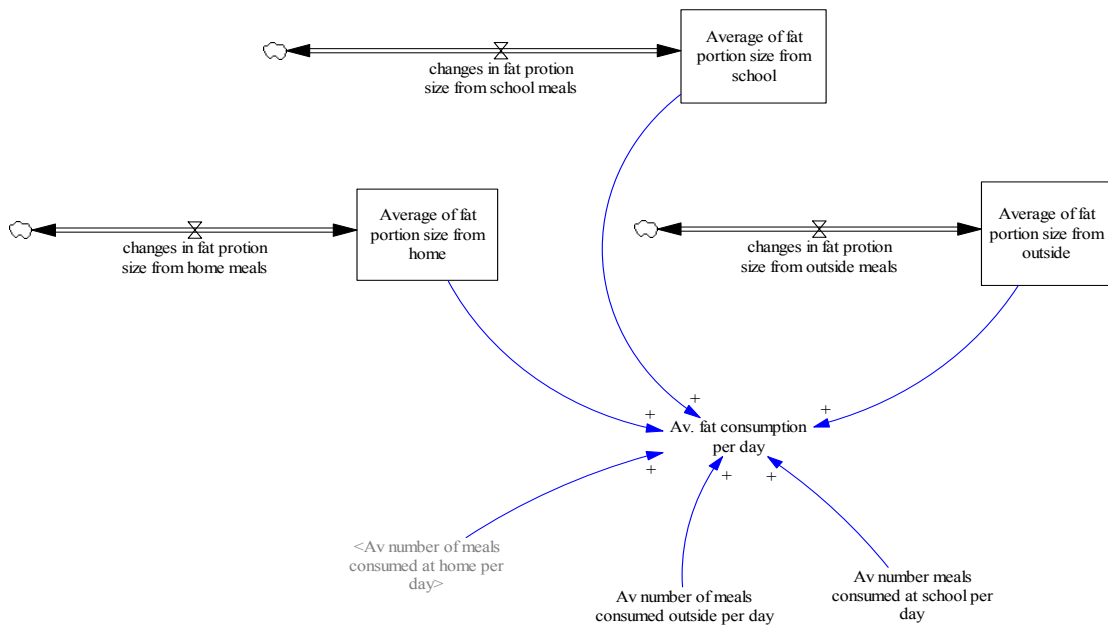


Figure 1: Structure for modelling average daily fat consumption; a similar model structure is developed for carbohydrate and protein portion sizes.

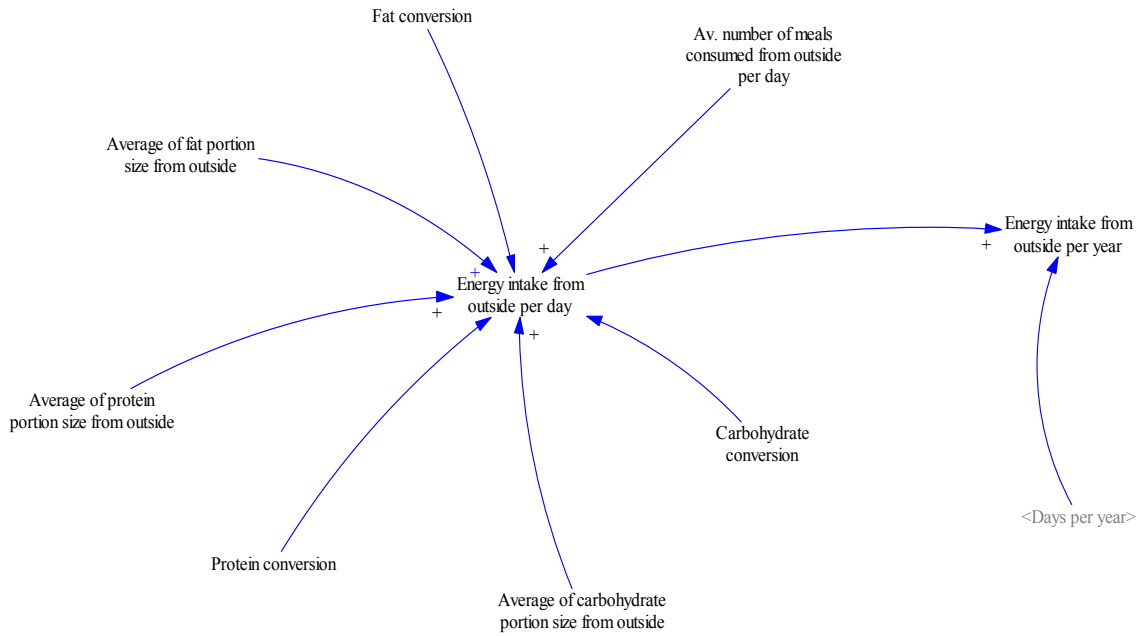


Figure 2: Structure for measuring daily and annual energy intake from meals taken outside the home; a similar model structure is developed for energy intake derived from home and school meals.

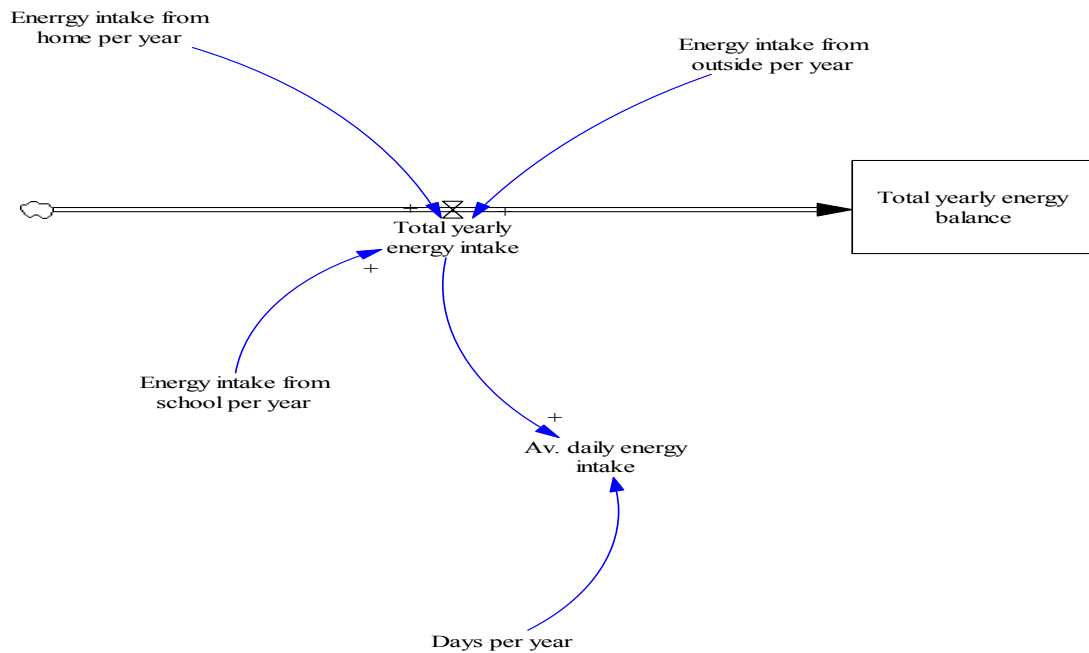


Figure 3: Model structure to represent total energy intake

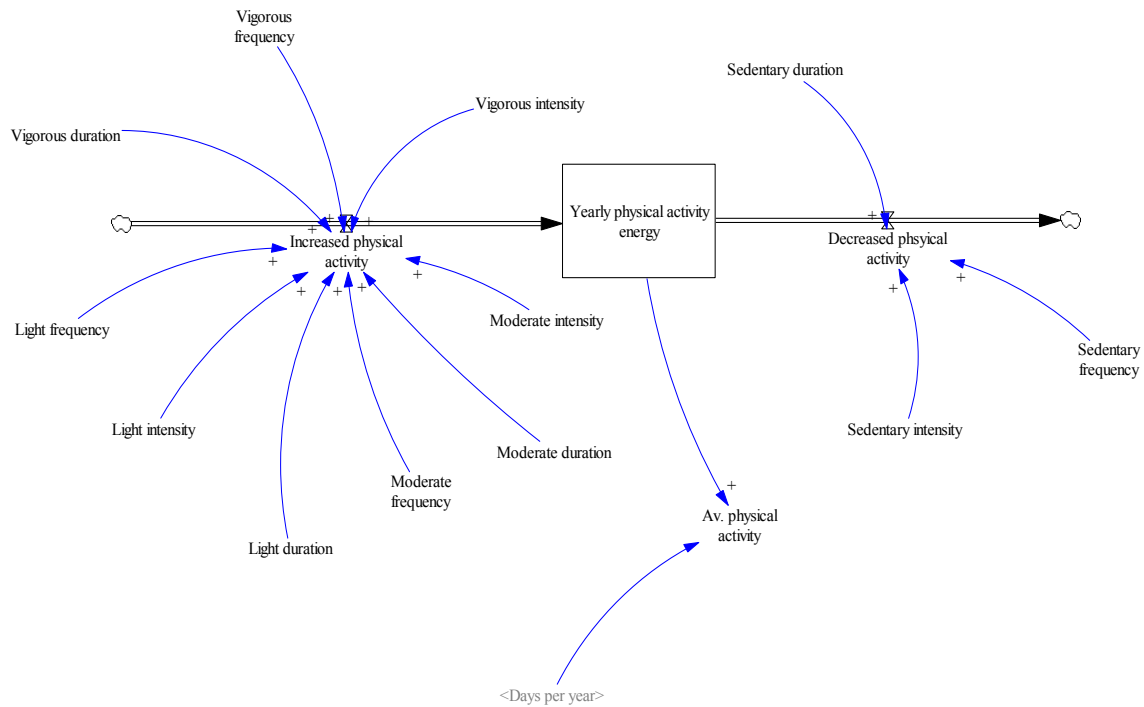


Figure 4: Model structure for measuring energy expended from physical activity

The basic model structure used for the overall obesity process is illustrated in figure 5. The aim here is to hypothesise and synthesise ideas about the workings of the obesity process, taking into account energy intake, energy expenditure, energy balance, weight and body mass index. A daily positive energy balance is stored in muscle or fat. An increased body weight itself, however, causes higher energy expenditure, specifically energy from the basal metabolism rate. An equivalence between energy intake and energy expenditure (equilibrium in energy balance) will ensure no weight change. The entire process can take years to show up as changes in the average weight of the population (Homer et al. 2004). The model is calibrated in years and so changes in daily energy balance and weight variability are smoothed out to result in a less sharp average weight change in a year. However, because eating and performing physical activity is a daily process, the model additionally computes energy intake and energy expenditure in daily units (kcal/day) to aid understanding and to reflect common health nomenclature.

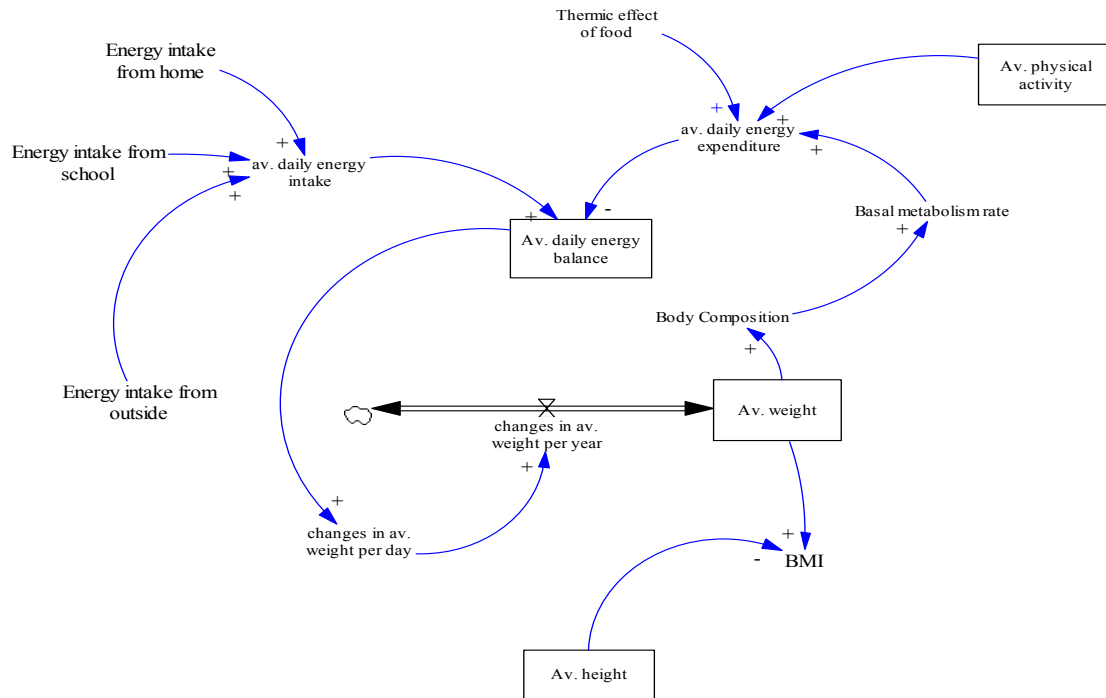


Figure 5: Interaction of energy intake, energy expenditure, energy balance, weight and body mass index (adapted from Homer et al. 2004 and Abdel-Hamid, 2002).

The above description exhibits a conceptualisation which is rich in detail concerning age groups and gender, the locations where food is consumed by children, the energy-giving components of food and the various ways that energy can be burned; in particular different levels of physical activity and the incidence of sedentary behaviour. Some models may exhibit a simpler structure but we believe our formulation creates a richer policy space which allows more detailed interventions to be explored. A high-level map of the current version of the model, reflecting the above dynamic hypothesis, is included as an appendix.

Before these experiments can be conducted, we need to calibrate the model. In public health research model calibration procedures can involve the use of literature data, simple calculations and judgemental estimation (Taylor et al. 2005; Sterman, 2000). Data from the literature refers to the use of parameter values obtained from relevant publications. Some of the parameters have been obtained from important studies by Abdel-Hamid (2002 and 2003), Homer et al. (2004) and Butte et al. (2007), as well as human physiology texts for known energy conversion coefficients. The second approach involves simple calculations and relates to the use of simple statistical estimations from the numerical data obtained from the Health Survey England from 1995 to 2009. The final approach of judgemental estimation has not been adopted here. This form of estimation is done by guessing a value for a parameter and then running the model repeatedly with a range of such trial values until a match is found between the real and observed behaviour patterns.

3 MODEL VALIDATION

Validation tests have been carried out to gain confidence in our model structure and the behaviour produced from the model. These tests include structure verification, parameter verification, dimensional consistency, extreme condition, behaviour reproduction and behaviour sensitivity. The choice of the tests employed is based on the purpose of the model (Sterman, 2000). For structure and parameter verification, the tests involve comparing how well the structure and parameter values adopted match the real system. Both tests are completed by reference to prior literature such as Abdel-Hamid (2002 & 2003), Homer et al. (2004 & 2006) and Butte et al. (2007). Currently, the model contains 378 equations and mappings. Each of these passes the dimensional consistency test. For the extreme condition test making constant the parameters associated with energy balance and height results in the unchanging weight and body mass index (BMI) behaviour demonstrated in Figure 12. This result equates with a condition where energy balance is maintained over a lengthy period and a person is considered to be in a steady-state or stable weight. In that situation energy intake and energy expenditure will be the same (FAO/WHO/UNU, 2004). We now turn to the behaviour reproduction test. The output from this test is presented in figures 8 and 10. Both figures demonstrate that behaviour patterns produced from the model align with the reported historical data obtained from the Health Survey England (1995 to 2009). The final test is a behaviour sensitivity test which is applied to explore the sensitivity of model behaviour to variations in the parameters (constants) in the model. This particular test can be performed in a number of ways and dynamic optimisation is one of the possible methods. Details of the optimisation results are discussed in Section 6.

4 SOME BASE CASE RESULTS FROM THE MODEL

The work reported here has been influenced by previous system dynamics modelling studies conducted by Abdel-Hamid (2002; 2003) and Homer et al. (2004; 2006). Their work has been used as a guideline for our modelling work, although there are differences in model detail and, to an extent, model purpose.

Although obesity occurs due to an increase in food intake and lack of physical activity (WHO, 2011; Butland et al. 2007; Kumanyika et al. 2002; Crawford and Ball, 2002), the approach used in this research to model obesity has taken into consideration that obesity develops due to feedback control between food intake, energy expenditure and fat stores as specified by Lambert and Goedecke (2003), Homer et al. (2004) and Abdel-Hamid (2002; 2003). In an earlier paper (Dangerfield and Abidin, 2010), we described the framework necessary to understand the influence of energy intake (EI), energy expenditure (EE) and energy balance (EB) on the average weight, BMI and prevalence of obesity in a population of children. This research attempts to explore the interactions between EI, EE and EB. EB is the difference between EI and EE. Both food intake and physical activity energy are investigated. A previous study by Egger and Swinburn (1997) stresses that weight is gained because EI is greater than EE, EE less than EI or both phenomena occur. In simple terms, weight gain is caused by eating more energy-giving nutrients than energy burned. The opposite result of weight loss occurs if EI is less than energy expenditure.

The following scenarios report on outputs from the base case model (Current). The aim is to provide an understanding of the values and behaviour patterns exhibited by these variables (EE, EI and EB) together with their impact on the physical measurements and obesity prevalence in the child population (aged 2-15 years).

Scenario 1: Here the objective is to investigate the impact of EI and EE on the EB and consequently on average weight. If EI is greater than energy expended, it creates a positive EB. The illustrations are for the male age group aged 11-15 years, one of six age/gender groups considered (see the appendix). Accumulation of a positive daily EB results in weight gain as shown in Figure 6 below. Figure 7 illustrates the opposite scenario; here weight decreases due to a negative EB.

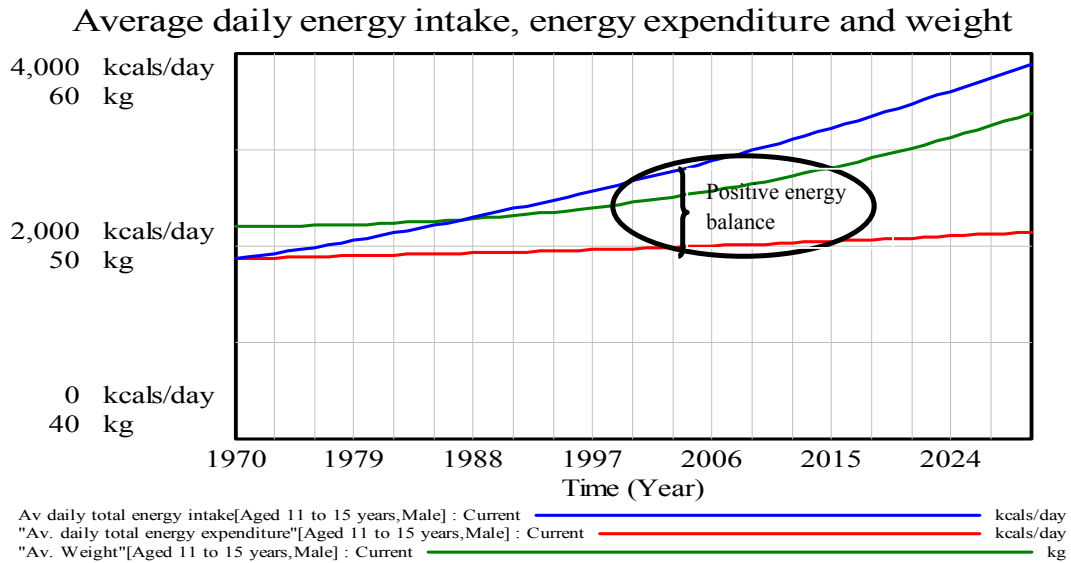


Figure 6: Increase in average weight due to higher energy intake than energy expenditure

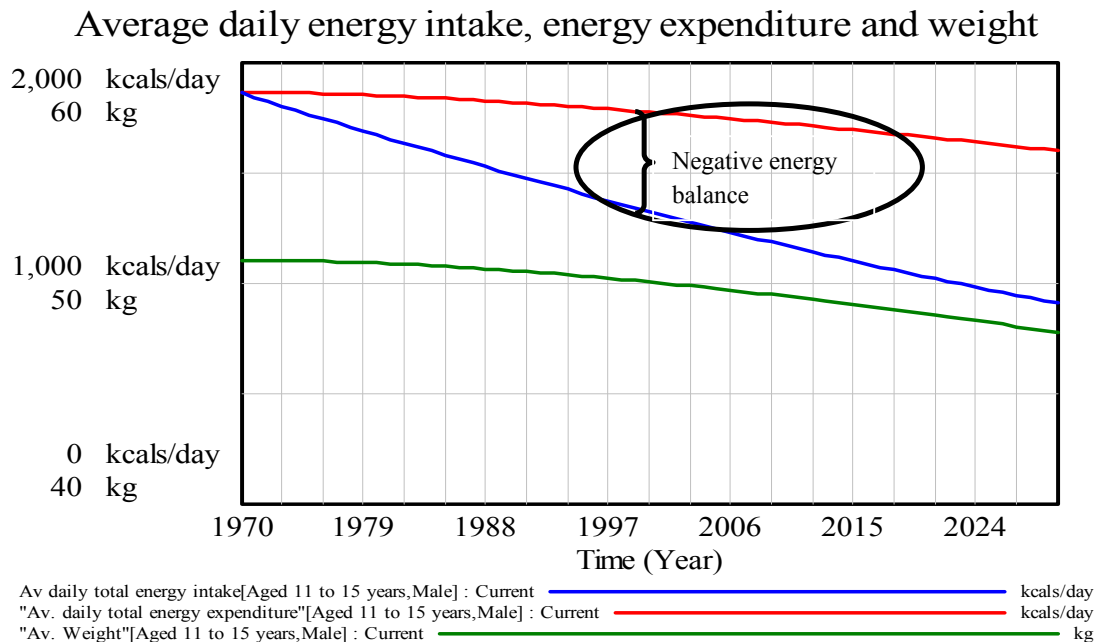


Figure 7: Reduction in average weight due to higher energy expenditure than energy intake

Scenario 2: In this instance the objective is to demonstrate the impact of changes in average weight and height on BMI. As average weight increases (decreases), whilst average height has

changed very little in the age groups over the sixty years considered, BMI increases (decreases) in value. The BMI value is measured using the standard formula: $BMI = \text{weight} / (\text{height} \times \text{height})$. The units are in kg/metres-squared. We have tested this formulation in the model. Figures 8 and 9 demonstrate the results obtained from the base case model. Both figures depict that with increasing (decreasing) values for average weight and the little change in average height, the BMI reflects a similar increasing (decreasing) value and behaviour pattern. For figure 8 the reported data for 11-15 year-old males is also included and the fact that the model trajectory is within the broad range of reported data is encouraging.

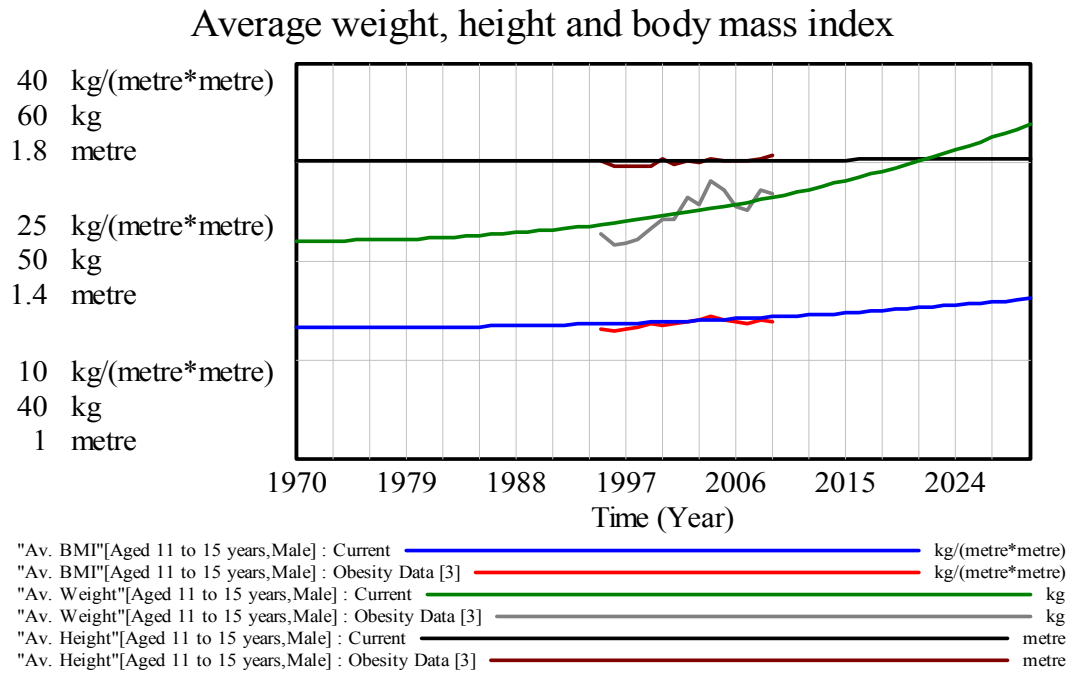


Figure 8: Increasing weight and BMI behaviour pattern

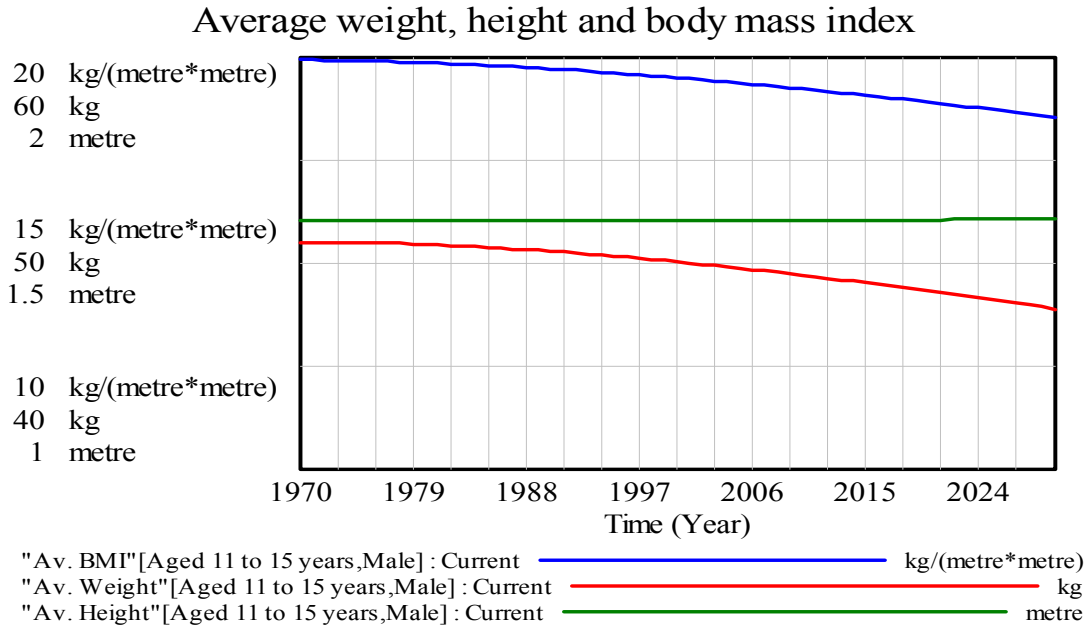


Figure 9: Decreasing weight and BMI behaviour pattern

Scenario 3: Here the objective is to demonstrate the impact of BMI on the prevalence of obesity. With increases (decreases) in the BMI value, the prevalence of obesity follows a similar behaviour pattern. Figures 10 and 11 illustrate the behaviour produced for both cases: increasing (figure 10) and decreasing (figure 11). Included in figure 10 is the reported data for males aged 11-15 years.

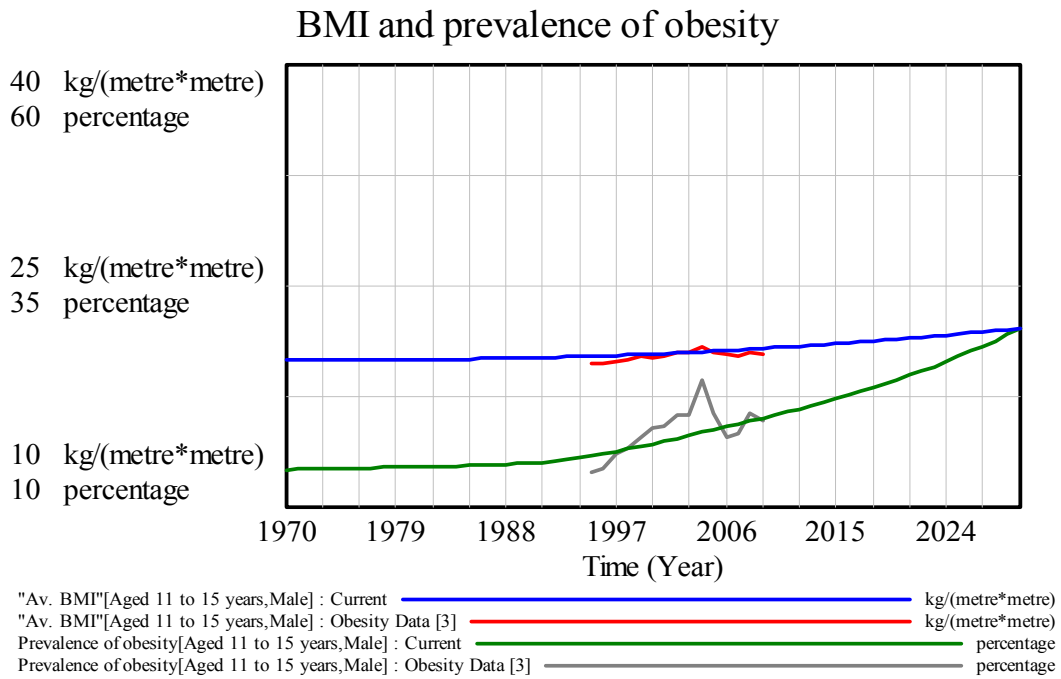


Figure 10: Increase in BMI results in an increased prevalence of obesity

BMI and prevalence of obesity

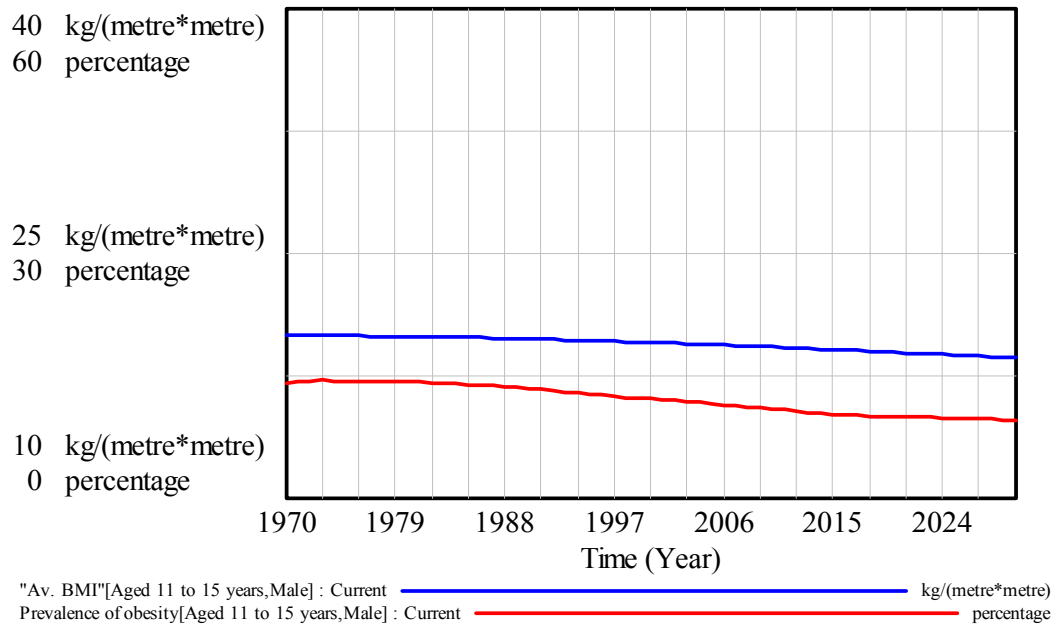


Figure 11: Decreasing BMI results in a decreasing prevalence of obesity

Scenario 4: A final scenario is reported to demonstrate an extreme case. If the height and EB is indeed in balance throughout time (so that there is a zero energy gap), then the average weight and BMI is also unchanged (figure 12).

Av. energy balance, height, weight and BMI

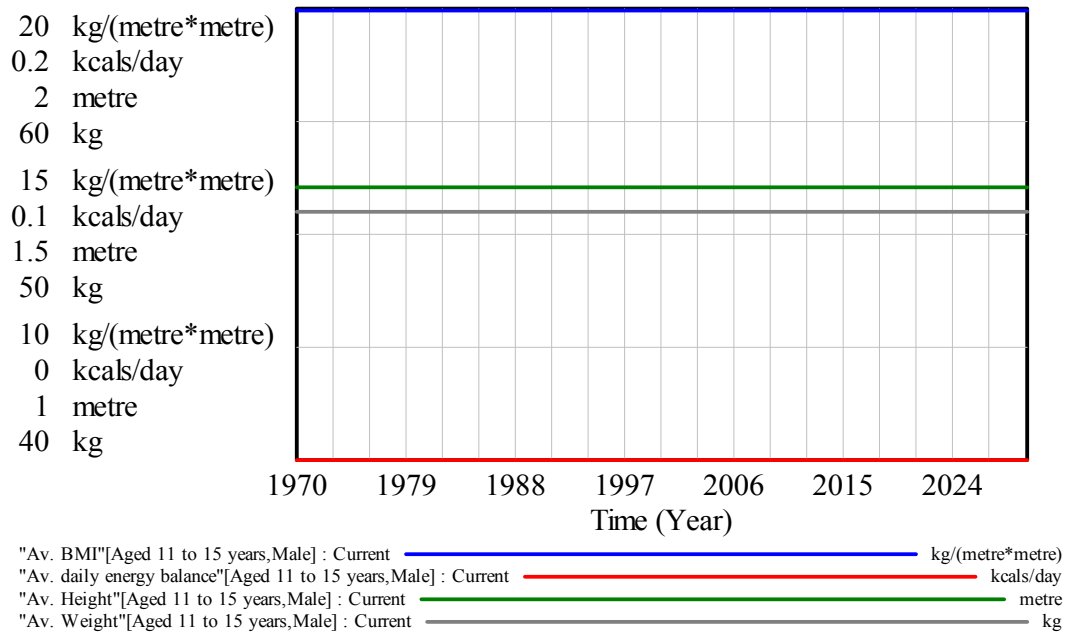


Figure 12: A constant energy balance yields a constant average weight and BMI

The output runs from these base case scenario projections allow us to have confidence that the model is producing results which are intuitive and which do not markedly differ from real-world reported data, at least for the child age group we have been able to obtain data for.

5 EXPLORING BEHAVIOURAL CHANGES

Here we examine certain behavioural changes: specifically these reflect broad modifications in eating habits and physical activity patterns and which are assumed to have taken place from the baseline year of 1970. The objective here is to develop further confidence in the model as a tool for investigating the consequences of such changes rather than (yet) simulating the effects of any specific population level interventions which obviously could happen only after the present day. As mentioned in the previous section, adverse changes in eating and physical activity behaviour have contributed positively to the developing trends in obesity prevalence. Therefore we have conducted two explorations in eating and physical activity patterns. For illustrative purposes the graphs depict the results for 11-15 year old males.

Behaviour Change 1: *Increasing fat intake to 40% while maintaining physical activity*

In the first behaviour change, the aim is to examine the impact of eating behaviour on the average weight, BMI and the prevalence of obesity. Increasing the proportion of fat in the diet to 40%, as compared with the base case value (35.4%), clearly contributes to an increase in the total energy intake. Compared to the base case run (figure 6), the total amount of energy intake is now changed from 1857 kcal/day to 1999 kcal/day in 1970 and, if this new fat proportion was maintained to 2030, it would reach 4169 kcal/day at that time (figure 13). The pattern of energy intake generates an increasing trend over the simulated 60 year period because of the fractional growth rate in portion sizes from outside, school and home meals. A similar increasing pattern is observed for average weight and (very slightly) for energy expenditure. As long as a positive energy balance (gap) is maintained (energy intake-energy expenditure), average weight will also follow an increasing trend. Weight is shown to increase from 51 kg in 1970 to 52.8 kg in 2000 and is predicted to increase again to 58.2 kg in 2030 if the revised fat proportion in the diet is maintained.

Figure 14 illustrates the linkage between weight and BMI. With the increasing average weight, the BMI trend also increases over time. Average BMI is only 19.9 kg/metre² in 1970. The value increases to 20.0 kg/metre², 20.2 kg/metre², 20.6 kg/metre², 21.1 kg/metre², 21.7 kg/metre² and to 22.6 kg/metre² in 1980, 1990, 2000, 2010, 2020 and 2030 respectively. A similar increasing pattern is observed for the prevalence of obesity. The higher the average BMI value obtained, the higher the prevalence of obesity, as would be expected. Figure 15 portrays this situation; the prevalence of obesity, only 14% in 1970, is now projected to increase to 34.4% in 2030.

Energy intake, energy expenditure and weight

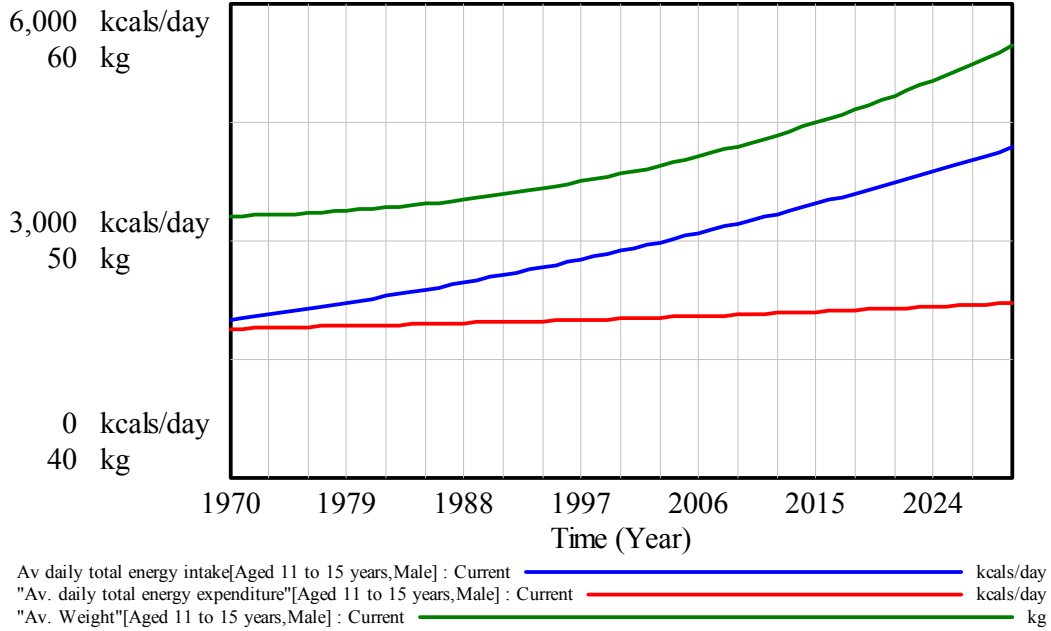


Figure 13: Increasing energy intake through increased fat consumption causes a rise in average weight (energy expenditure more or less constant)

Weight, height and body mass index

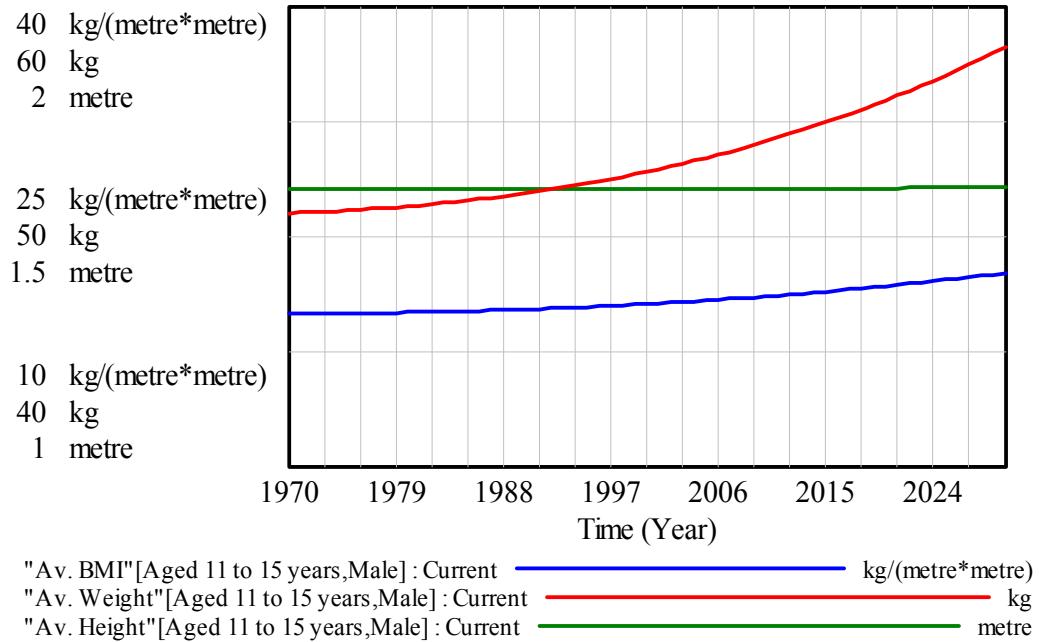


Figure 14: Increasing weight associated with the experiment depicted in the previous figure produces a linked increase in BMI

BMI and prevalence of obesity

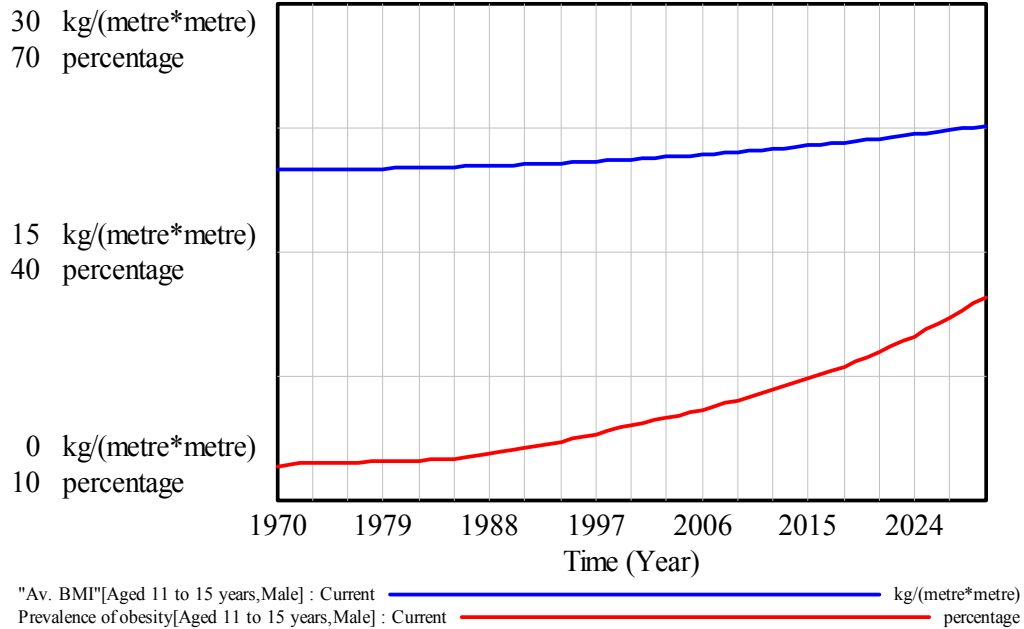


Figure 15: Increasing BMI causes an increase in the prevalence of obesity

Behaviour Change 2: *Maintaining food intake but increasing energy expended from physical activity to 40% of the total*

In the second behaviour change, the aim is to examine the impact of changes in physical activity on weight, BMI and prevalence of obesity. Energy expended from physical activity is increased to 40% of the daily total (base case= 13.2%) with commensurate reductions in the percentages for the Basal Metabolism Rate and the Thermic Effect of Food to absorb the change from 13.2% (see appendix). This renders the initial value for total energy expenditure to be increased from 1858 kcal/day (base case) to 2688 kcal/day (intervention) in 1970. The model output (figure 16) demonstrates that, from 1970 to 2001, average weight is reduced and then it starts to stabilise (and even increase) between 2001 and 2030. The reduction in weight occurs because energy expenditure is higher than energy intake and this has created a negative energy balance/gap over the first 31 years. The slight increase observed in the final 29 years is because the assumed change in the proportion of energy expenditure due to physical activity, which changes the trajectory of the energy expenditure curve from the base case situation, is still not sufficient to keep it above the base case (see figure 16) trajectory of energy intake for the entirety of the run. Accordingly, there is a slight increase in average weight in the final 29 years of the run.

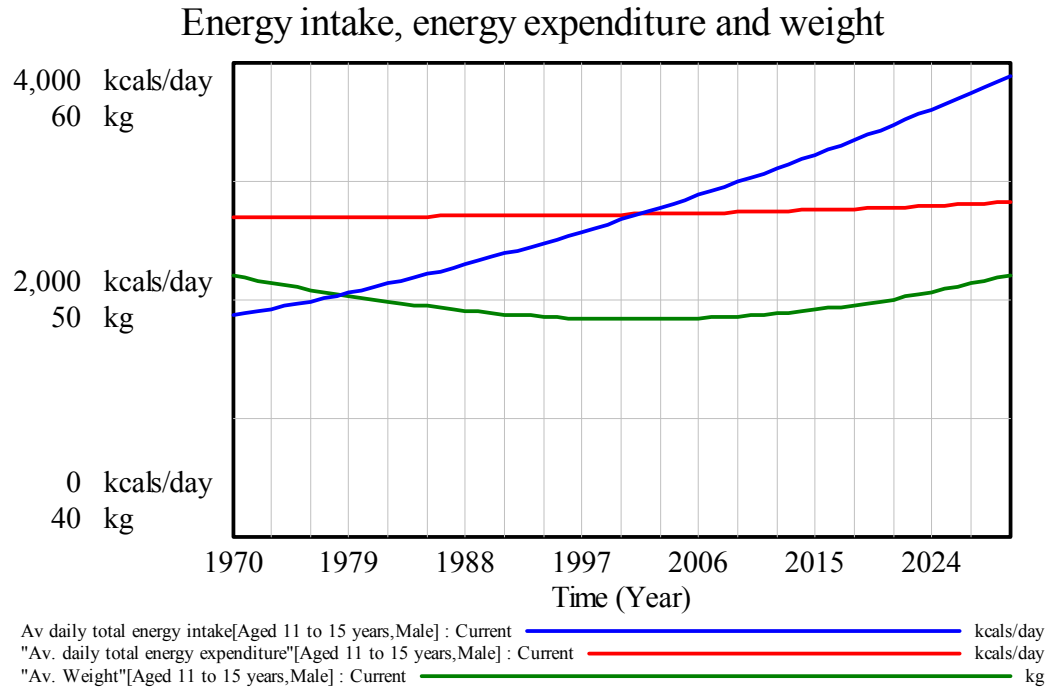


Figure 16: Relationship between energy intake, energy expenditure and weight

With a reduction in average weight over the first 31 years of the run, BMI also reduces similarly (figure 17), although again a slightly increase occurs after 2001. Average BMI decreases from 19.9 kg/metre² in 1970 to 19.1 kg/ metre² in 2000. The BMI value then increases to 19.4 kg/metre² and 19.8 kg/metre² in 2020 and 2030. A similar behaviour pattern is observed in the prevalence of obesity (figure 18). The prevalence, 14% in 1970, decreases to 11.0% in 1990 and reaches 11.4% in 2020.

Weight, height and body mass index

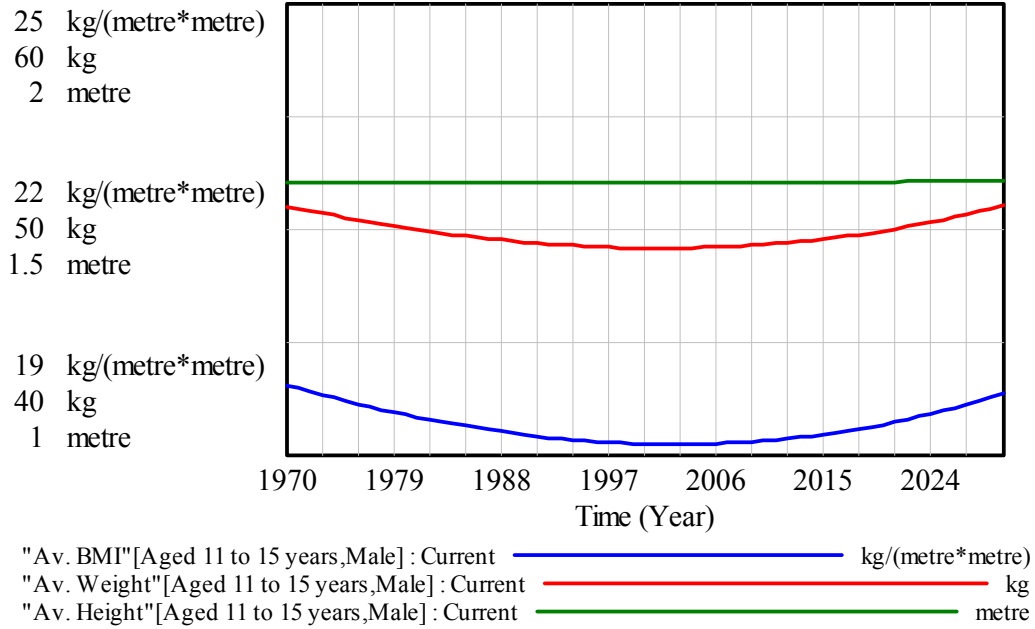


Figure 17: Relationship between average weight and BMI

BMI and prevalence of obesity

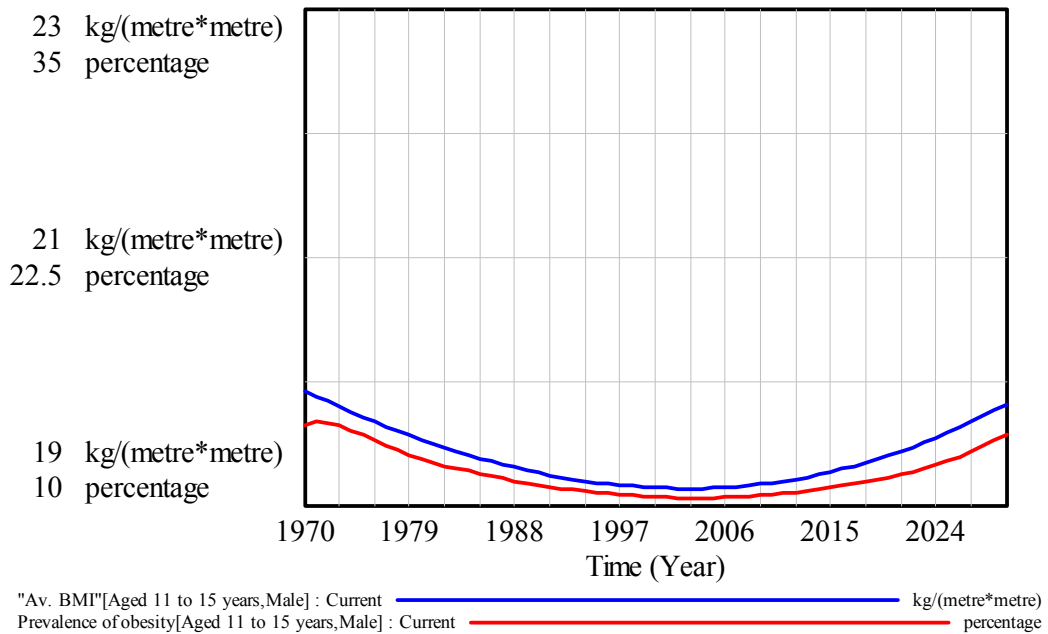


Figure 18: Relationship between BMI and obesity prevalence

Some conclusions may be drawn from the output graphs of the two interventions. These results support the view that eating more food, particularly energy-dense foods with a high fat content, yet maintaining physical activity patterns, results in an increase in average weight, BMI and obesity prevalence. For the energy expenditure experiment the modification was effected through an adjustment to the proportion of physical activity undertaken. With the energy expended from physical activity increased to 40%, whilst maintaining the same food intake, a decrease in average weight, BMI and obesity prevalence is the result, followed later by a rise for the reasons given above.

6 IDENTIFYING THE MOST EFFECTIVE BEHAVIOURAL CHANGE USING OPTIMISATION

Once confidence has been developed in terms of the model’s structure and behaviour, a series of experiments are possible to help in the policy-making process. This work thus adds to the swathe of research activity designed to highlight the most effective behavioural change strategies for child obesity amelioration. Specifically, this section aims to make a comparison between changes in eating and physical activity behaviour. Which is the most effective strategy for reversing trends in child weight, BMI and prevalence of obesity? The results are presented from a total population perspective (2-15 years) as a broad strategy to tackle obesity at the population level. The population sector in the model allows the determination of relevant metrics over the full age range by using weighted average calculations.

Dangerfield (2009) reiterates that there are two categories of optimisation in system dynamics: policy optimisation and calibration optimisation. The first type called *policy optimisation* is related to parameter changes which make improvements in model performance, for instance to maximise sales revenue or to minimise costs. The other type, known as *calibration optimisation*, involves the optimisation process searching for the parameter vector offering the best fit to a given data series. This research applies the latter option: to identify the most effective behavioural change strategies which achieve a desired weight target in 2020. However, since this involves a *future* data series (as opposed to the more normal practice of fitting to *past* data in calibration optimisation) the overall process is effectively a hybrid of policy and calibration optimisations. The date of 2020 is important because the UK government has set a target to reverse the obesity metrics back to 2000 levels by 2020 (Department of Health, 2008). This aim can obviously be achieved through changes in average weight. Table 1 presents a plausible average weight target needed by 2020 and figure 19 illustrates a graph for weight changes from the baseline, starting in 2013, that would be compatible with UK government policy. The blue line in figure 19 shows the trend for the total average weight from the simulated model (base case) whereas the red line is a desired weight trajectory which passes through the target needed by 2020 (=34.6 kg). Obviously the trajectory could be different with a slower initial decrease and then a sharper fall to the target value in 2020. We have not yet explored other possible trajectories.

Table 1: Changes in total average weight value for the past (1970-2010) and future (2020-2030)

	1970	1980	1990	2000	2010	2020	2030
Total average weight (kg) (Baseline)	32.40	34.06	33.91	34.55	35.55	36.69	38.56
Desired total average weight (kg)						34.55	34.31

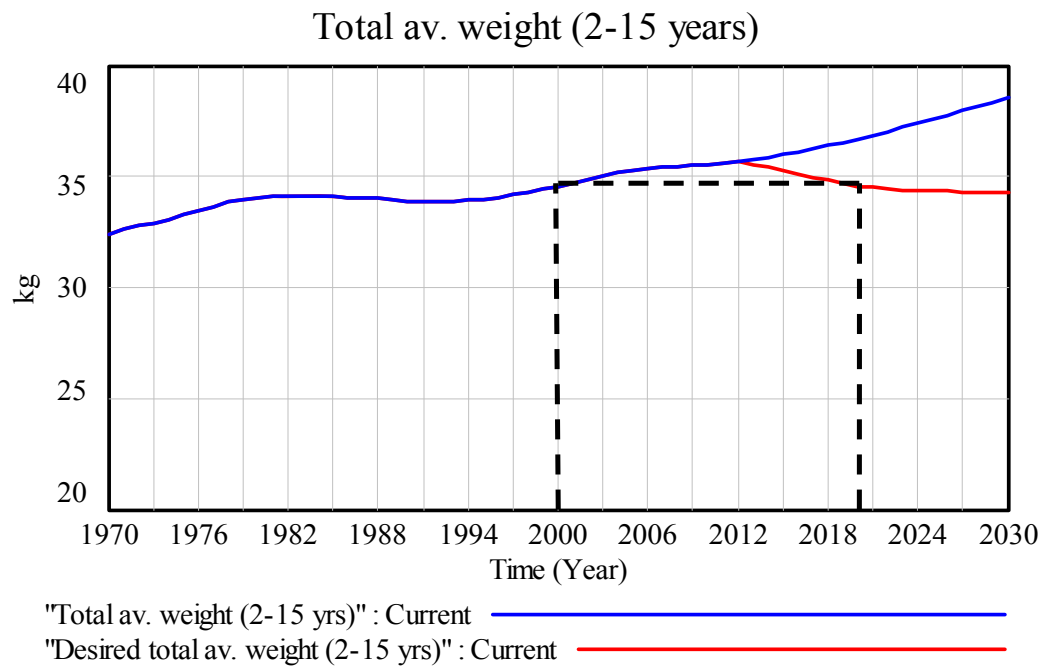


Figure 19: Base case trajectory for total average weight (blue line) and a plausible desired total average weight (red line) to achieve the target in 2020

In order to achieve the desired weight target of 34.6kg in 2020, behaviour changes must be made in eating or physical activity or both. To be specific, the behavioural changes evaluated in this research are achieved through two strategies which are: (1) improved food intake and (2) increased physical activity with a concomitant reduction in sedentary behaviour. The changes can only take place in the future so we have chosen 2013 for the policy changes to be rolled out.

Further, public policy changes cannot produce a sudden, step response so we have optimised on rate of change parameters which are assumed to change in a gradual linear fashion over a period of years. This is managed in the model using the RAMP function, one of the functions available in the VensimTM software. In order to attempt to achieve the necessary reduction in average weight by 2020, the optimisation process was performed on rates of change in eating and physical activity variables. It is reflected in the structure of equation 1 below. This generalised equation can be applied to both eating and physical activity parameters, although the sign needs to reflect whether a reduction or an increase is desirable. Changes in behaviour are assumed to commence in 2013. The aim of the interventions is to encourage future child generations to adopt healthy eating and physical activity behaviour and consequently improve their health in general. Alterations made in eating and the physical activity parameters work by decreasing the amount of EI and increasing both physical activity energy and total EE. Changes which occur in both EI and EE result in changes in EB. The greater the reduction in EB, the more average weight is reduced.

$$\text{Parameters} = \text{Initial value of parameters} - \text{RAMP}(\text{slope of change}, 2013, 2030) \dots \quad (1)$$

The first experiment concerns changes made in eating behaviour. The baseline model (see figure 20) demonstrates that average daily energy intake increased between 1970 and 2030. The aim of the eating optimisation is to investigate the impact of a reduction in the amount of energy intake on average weight, BMI and the prevalence of obesity. In this experiment, changes are made in two eating parameters while all physical activity parameters are held as they were in the base case. There are seven parameters which are potentially useful for the experiment. However, we chose only two parameters for the eating optimisation experiments. These are *the fractional growth rate in total meals consumed per year* and *the fractional growth rate in the fat portion size for outside meals*. These two have the greatest influence on the determination of EI.

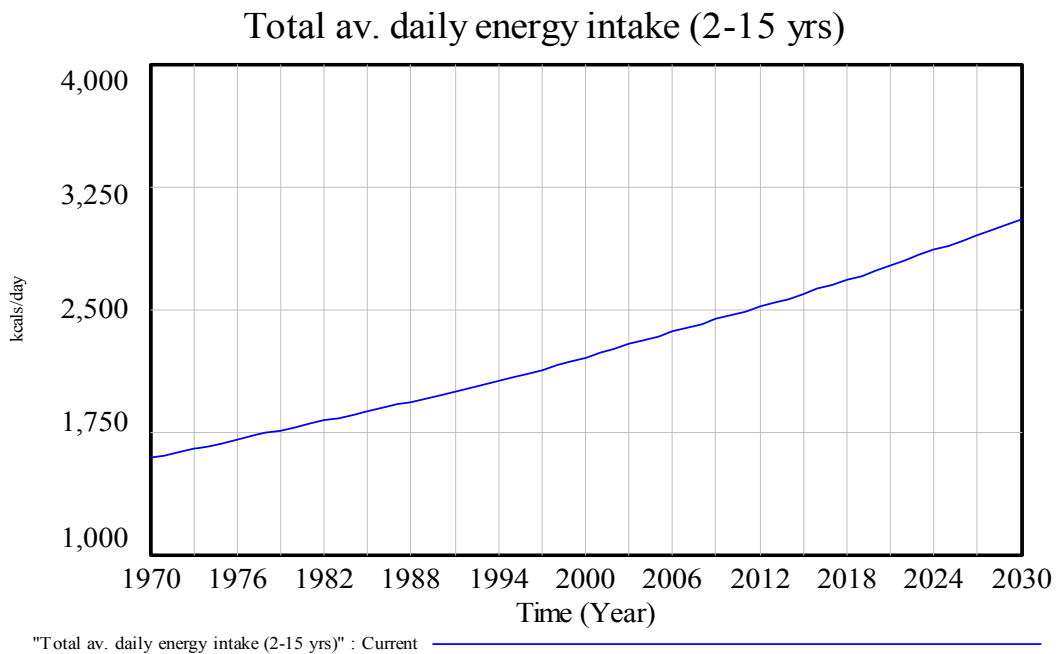
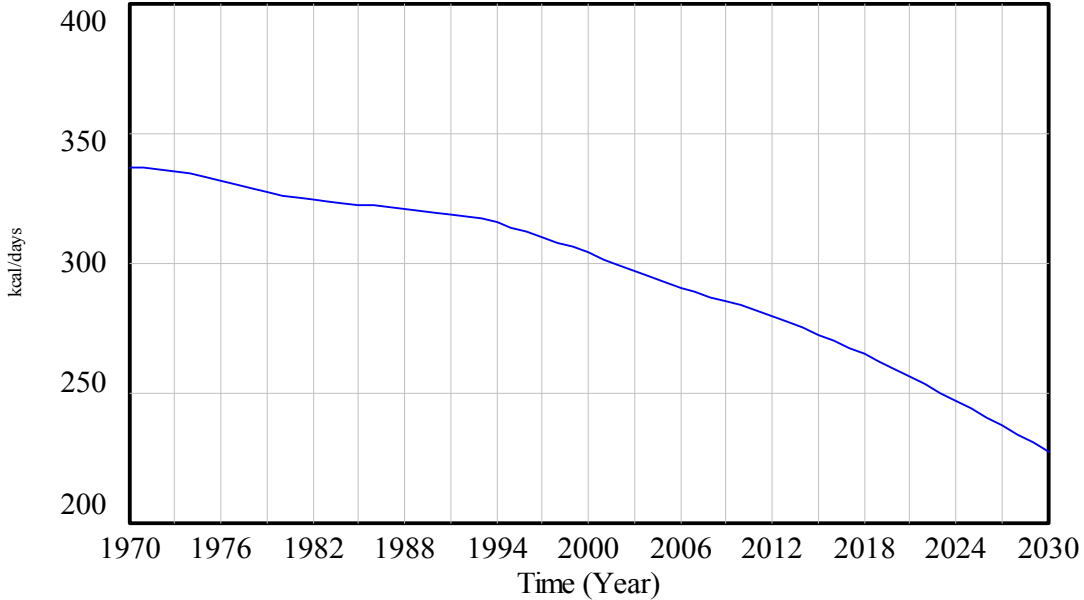


Figure 20: Increased in energy intake between 1970 and 2030

The second experiment involves changes in activity behaviour. From the baseline model, physical activity energy expenditure decreases between 1970 and 2030 as shown in figure 21. Using optimisation, the aim is to increase the amount of physical activity energy from 2013 to 2030. There are seven possible parameters in the list of potential parameters to be optimised, targeting on intensity and frequency. For the purpose of PA optimisation, only five parameters are selected as follows: (1) *metabolic rate involved in vigorous activity*, (2) *metabolic rate involved in moderate activity*, (3) *fractional change rate in frequency per year of vigorous activity*, (4) *fractional change rate in frequency per year of moderate activity*, and (5) *fractional change rate in frequency per year of sedentary behaviour*. Changes in all these parameters result in beneficial changes occurring in the amount of physical activity energy expended.

Total av. daily physical activity (2-15 yrs)



"Total av. daily physical activity (2-15 yrs)" : Current

Figure 21: Reduction in physical activity energy expended between 1970 and 2030

During the optimisation process, both eating and physical activity parameters are optimised for the six age groups and gender (2-4 years, 5-10 years, 11-15 years, for both males and females). From the eating optimisation, the average daily EI was reduced by means of a reduction in the total meals consumed (eating episodes) per year and in the fat portion size of outside meals. By contrast, the output obtained from the physical activity optimisation results in an increase in the average daily physical activity energy expended and this is accomplished through an increased frequency and intensity of moderate and vigorous activity and a decreased frequency of sedentary behaviour. Incorporation of the optimum parameter values in the model each, separately, yields a decrease in total average weight against the base case (not shown) – see figures 22 and 23.

The first finding from the eating (strategy 1) and physical activity (strategy 2) optimisation experiments is that induced changes in the eating parameters offer the best means of a reduction in average weight and provides the closest solution to the desired weight target in 2020. To be more specific, the baseline results reveal that the total average weight in 2020 is 36.8 kg and after eating optimisation, the total average weight in 2020 reduces to 35.6 kg. However, it does not get below the target for 2020 until 2026. Similarly, the total average BMI is 19.7 kg/m² at baseline and this reduces to 19.1 kg/m² in 2020. Finally, the prevalence of obesity also exhibits a similar reducing value from 24.0% in 2020 (baseline) to 21.1% in 2020 after the optimisation process.

In the physical activity optimisation, the total average weight in 2020 is 36.79 kg (baseline) and this reduces to only 36.68 kg after optimisation. In 2030, the total average weight is 38.56 kg at baseline, slightly reducing to 38.44 kg after optimisation. Similarly the BMI also exhibits a very slightly reduced value: average BMI in 2020 is 19.70 kg/m² (baseline) decreasing to 19.69 kg/m² after optimisation. Clearly the prevalence of obesity will mirror this fall: 24.04% in 2020 (baseline) against 24.02% after optimisation. The prevalence falls further by 2030 where in the baseline the percentage is 28.75% reaching 28.51% after optimisation. A tabulated comparison of both of the eating and physical activity optimisation experiments with the baseline is presented in Table 2.

There is support for this finding in the public health literature. Skender et al. (1996), Ebersole et al. (2008), Epstein et al. (2001) and Swinburn et al. (2009) all offer the view that changes in modifying energy intake are more important compared to physical activity for obesity amelioration. One possible explanation is there are no significant differences in physical activity between obese and non-obese adults and children as suggested by Ebersole et al. (2008) and Epstein et al. (2001). A second explanation is that although children can increase their physical activity energy expenditure, they still continue to consume an increasing energy intake (EI) at the same time. This makes it harder for physical activity behavioural changes to achieve the required amount of average weight reduction. By contrast, any beneficial reduction in energy intake cannot be overcome by changes on the energy expenditure side because the changes underway in reducing activity and increasing sedentary behaviour are not as fast-moving as those on the energy intake side of the balance.

A second finding is that the achievement, in both average weight and prevalence, of the government’s desired target is unlikely to be met by 2020. It may be possible by 2026 and can only be achieved by adjusting eating behaviours. Physical activity changes alone will not allow the target to be achieved at any point throughout the entire intervention period (2013-2030).

However, we express the caveat here that all these results derive from a limited set of parameter combinations upon which we have experimented in the model. It may be possible to uncover a combination which offers a significantly improved leverage, although our work thus far suggests this is unlikely.

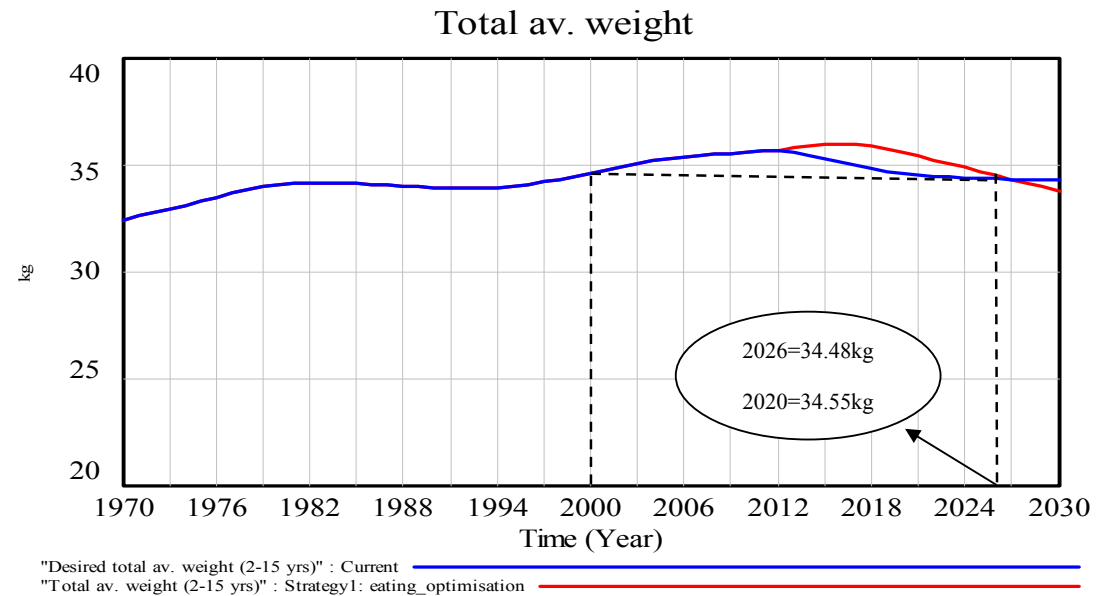


Figure 22: Comparisons of eating optimisation (red line) with the desired target (blue line) for the total average weight between 2013 and 2030

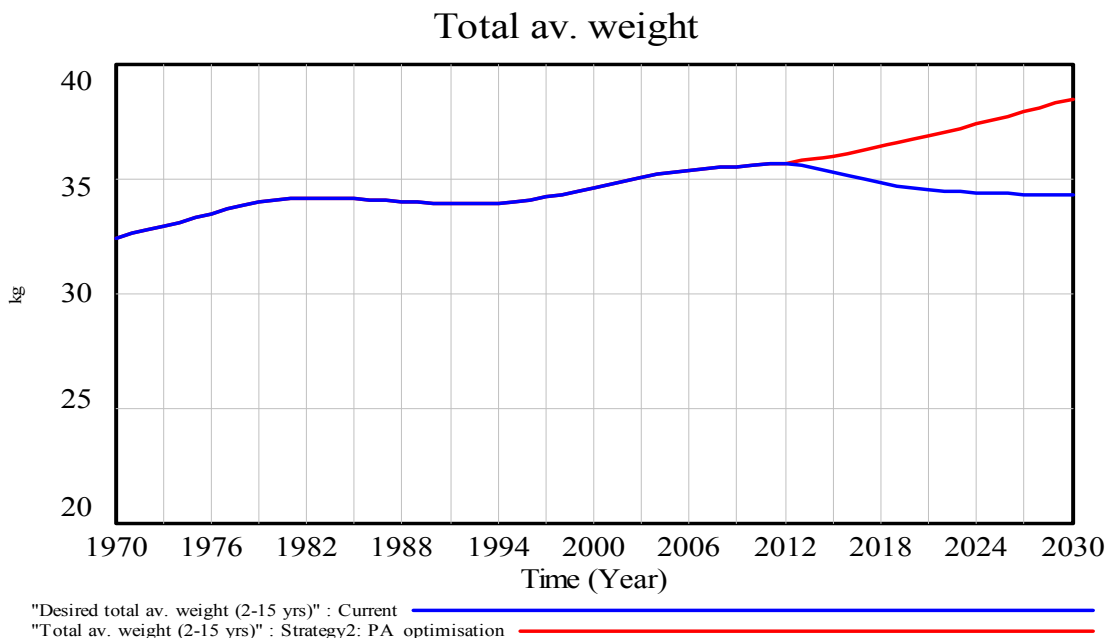


Figure 23: Comparisons of physical activity optimisation (red line) with the desired target (blue line) for the total average weight between 2013 and 2030

Table 2: Comparisons of total average weight, BMI and prevalence of obesity changes resulting from two optimisation strategies

Baseline and intervention strategies	Total average weight (kg)		Total average BMI (kg/m ²)		Prevalence of obesity (%)	
	Baseline	Optimisation	Baseline	Optimisation	Baseline	Optimisation
	1970	2030	1970	2030	1970	2030
	Baseline (Current)					
	32.40	38.56	17.98	20.61	12	28.75
	Strategy 1: Eating optimisation					
	32.40	33.76	17.98	18.02	12	12.21
	Strategy 2: Physical activity optimisation					
	32.40	38.44	17.98	20.55	12	28.51

7 SUMMARY

Eating more food and performing less physical activity are fundamental to obesity development according to the scientific literature. The process is derived from the creation of a positive energy balance when energy intake consistently exceeds energy expenditure. Output runs from the model have supported the view that if children derive more of their energy intake from fat and burn less energy from undertaking physical activity then population obesity metrics will turn adverse. Although the base case changes simulated above have been of a broad general nature, the results were encouraging enough to suggest that we could move forward and use the model to evaluate specific targeted interventions to ascertain the future effects on the English child population.

The most important objective of this first strand of our interventions analysis has been to compare changes in eating and physical activity behaviours in their role in childhood obesity amelioration. The results reveal that a modification made in eating behaviour is the most effective tool in this regard. The amount of average weight reduction from changes in eating behaviour is the closest we came to hitting the desired average weight target to be achieved in 2020. However, we found that the extent of change is still not enough to achieve the 2020 target. Therefore, it may be necessary to expand the intervention period in order to achieve the weight and prevalence of obesity target. This is true because the effects of a behaviour change process at the population level will take a significant time to have an impact. Further, findings from this research will deliver a message to policy makers, the food industry, practitioners and researchers of the importance of collaboration in order to fully and effectively explore potential strategies for reversing the obesity burden. This will help to achieve the UK government target of having a healthy child population in the future.

8 FUTURE WORK

One of the facets we are striving to understand is: what are the most influential factors motivating children to adopt either a healthy or a non-healthy lifestyle? Also, what can we say about the effect on important metrics as a consequence of such changes – in either direction? Positive behavioural change through an intervention surrounding these motivational factors would represent a major milestone in overcoming current trends. Much of the current public health research discusses the role of hard variables in physical activity and eating behaviour. *Hard factors* in this context refer to quantifiable variables such as the intensity and frequency of physical activity, for example. Turning to eating behaviours, examples include the number of meals taken per day and the frequency of eating and snacking. For any model, behavioural changes, involving *soft factors*, put more stress on the modelling technology and, in consequence, the scope of insights which can be gained. It is easy to simulate the effects of changes in hard variables (as we have done above) and many modelling methodologies would be capable of this. But public health experts require to know how best to *achieve* those changes in the child population. System dynamics is capable of incorporating soft factors into the model structure and, as such, by exploring these softer dynamics it offers something above and beyond other methodologies.

Behavioural change which concentrates on *soft factors* (e.g. attitude and perception) can also contribute to uncovering and suggesting effective interventions. Owing to the importance of soft factors as a contribution to influencing eating patterns and physical activity, further developments in this research will explore the socio-psychological *Theory of Planned Behaviour* (TPB) due to Ajzen (1991). TPB highlights the personal elements in the decision-making process and takes into consideration the view that a person's immediate surroundings shape their decision-making and their attitudes.

Future work will include the incorporation of a developed model structure for understanding physical activity and eating decision making processes, taking into account soft factors. Specific behavioural change interventions can then be conducted to identify what are likely to offer the most effective solutions to overcoming trends in obesity in the child population.

References

- Abdel-Hamid, T. K. (2002) Modelling the dynamics of human energy regulation and its implications for obesity treatment. *System Dynamics Review*, 18 (4), 431-471.
- Abdel-Hamid, T, K. (2003) Exercise and diet in obesity treatment: an integrative system dynamics perspective. *Medicine & Science in Sports & Exercise*, 35(3), 400-414.
- Ajzen (1991). The theory of planned behaviour. *Organizational Behaviour and Human Decision Processes*, 50: 179-211.
- Bowman, S. A. and Vinyard, B. T. (2004) Fast food consumption of U.S. adults: impact on energy and nutrient intakes and overweight status. *Journal of the American College of Nutrition*, 23(2), 163-168.
- Butland, B., Jebb, S., Kopelman, P., McPherson, K.M Thomas, S., Mardell, J. and Parry, V. (2007). Tackling obesities: Future choices-project report, 2nd edition. Report for Foresight, Government Office for Science. Available from: <http://www.bis.gov.uk/foresight/our-work/projects/published-projects/tackling-obesities/reports-and-publications> [Accessed 20 February 2009]
- Butte, N. F., Christiansen, E. and Sørensen, T. I. A. (2007) Energy imbalance underlying the development of childhood obesity. *Obesity*, 15(12), 3056-3066.
- Butte, N. F. (2000) Fat intake of children in relation to energy requirements. *The American Journal of Clinical Nutrition*. 72 (suppl), 1246S-1252S.
- Byrd, J. (2007). The impact of physical activity and obesity on academic achievement among elementary students. Available at <http://cnx.org/content/m14420/latest/> [Accessed 20 November 2010]
- Caballerro, B., Clay, T., Davis, S. M., Ethelbah, B., Rock, B. H., Lohman, T., Norman, J., Story, M., Stone, E. J., Stephenson, L. and Stevens, J. (2003). Pathways: a school-based, randomized controlled trial for the prevention of obesity in American Indian schoolchildren. *American Journal of Clinical Nutrition*, 38, 1030-1038.
- Choudhary, A. K., Donnelly, L. F., Racadio, J. M. and Strife, J. L. (2007). Diseases associated with childhood obesity. *American Journal of Roentgenology*, 188: 1118-1130.
- Crawford, D. and Ball, K. (2002) Behavioural determinants of the obesity epidemic. *Asia Pacific Journal Clinical Nutrition*. 11 (Suppl), S718-S721.
- Dangerfield, B. C. and Abidin, N. Z. (2010) Towards a model-based tool for evaluating population-level interventions against childhood obesity. In: *The Proceedings of 28th International System Dynamics Conference*, July 2010, Seoul, Korea, July 25-29, 2010.
- Dangerfield, B. C. (2009) Optimisation of system dynamics models. In: Meyers, R. A. (Ed) *Encyclopaedia of Complexity & Systems Science*, Springer, New York, USA. 9034-9043.
- Datar, A., Sturm, R. and Magnabosco, J. L. (2004). Childhood overweight and academic performance: National study of kindergartners and first grades. *Obesity Research*, 12:1, 58-68.
- Dehghan, M., Akhtar-Danesh, N. and Merchant, A. T. (2005) Childhood obesity, prevalence and prevention. *Nutrition Journal*, 4(24), 1-8.

Department of Health (2008) Healthy weight, healthy lives: A cross-government strategy for England. Available from: http://webarchive.nationalarchives.gov.uk/20100407220245/http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_082378 [Accessed 10 May 2009]

Ebersole, K. E., Dugas, L. R., Durazo-Arvizu, R. A., Adeyemo, A. A., Tayo, B. O., Omotade, O., Brieger, W. R., Schoeller, D. A., Cooper, R. S. and Luke, A. H. (2008) Energy expenditure and adiposity in Nigerian and African-American women, *Obesity*, 16(9), 2148-2154.

Epstein, L. H., Gordy, C. C., Raynor, H. A., Beddome, M., Kilanowski, C., and Paluch, R. (2001) Increasing fruit and vegetable intake and decreasing fat and sugar intake in families at risk for childhood obesity. *Obesity Research*, 9(3), 171-178

Egger, G. and Swinburn, B. (1997). An 'ecological' approach to the obesity pandemic. *British Medical Journal*, 315, 477-483.

FAO/WHO/UNU (2004) Human Energy Requirements. Report of a Joint FAO/WHO/UNU expert consultation. Food and Nutrition Technical Report Series 1, Food and Agriculture Organization, Rome.

Guo, S. S., Wu, W., Chumlea, W. C. and Roche, A. F. (2002) Predicting overweight and obesity in adulthood from body mass index values in childhood and adolescence. *American Journal Clinical Nutrition*, 76, 653-658.

Homer, J., Milstein, B., Dietz, W., Buchner, D., and Majestic, E. (2006), Obesity population dynamics: exploring historical growth and plausible futures in the US. *Procs of 24th International System Dynamics Conference*, July 2006, Nijmegen, July 2006.

Homer, J., Jones, D., Milstein, B., Murphy, D., Essein, J. and Seville, D. (2004). Diabetes System Model Reference Guidance. Revised Edition.

Ingalls, E.J., Kolesar, P. and Walker, W.E. (2008) Using simulation to develop and validate analytic models: some case studies. *Operations Research*, 26 (2), page: 237-253

Jéquier, E. (2001) Is fat intake a risk factor for fat gain in children? *The Journal of Clinical Endocrinology & Metabolism*, 86 (3), 980-983.

Kumanyika, S., Jeffery, R. W., MOrabia, A., Ritenbaugh, C. and Antipatis, V. J. (2002) Obesity prevention: the case for action. *International Journal of Obesity*, 26, 425-436.

Lambert, E. V. and Goedecke, J. H. (2003) Energy balance and energy expenditure in obesity- is obesity a disease of inactivity? *Sports Medicine*, Clinical Review, 21-25.

Levy, D. T., Mabry, P. L., Wang, Y. C., Gortmaker, S., Huang, T. T-K, Marsh, T., Moodie, M. and Swinburn, B. (2010). Simulation models of obesity: a review of the literature and implications for research and policy, *Obesity Reviews*, 1-17.

McPherson, K., Marsh, T. and Brown, M. (2007) Tackling obesities: Future choices-modelling future trends in obesity and their impact on health. Report for Foresight, Government Office for Science. Available from: <http://www.bis.gov.uk/foresight/our-work/projects/published-projects/tackling-obesities/reports-and-publications> [Accessed 20 February 2009].

National Obesity Observatory (2010). Key data briefings, Available from: http://www.noo.org.uk/NOO_pub/Key_data [Accessed on 31 May 2011]

NHS (2011) Statistics on Obesity, Physical Activity and Diet: England, 2011. The Department of Health, The Information Centre. Available from: <http://www.ic.nhs.uk/statistics-and-data-collections/health-and-lifestyles/obesity/statistics-on-obesity-physical-activity-and-diet-england-2011> [Accessed 15 Jun 2011]

NHS (2011) Health Survey for England-2009: Trend tables, The Information Centre, Available from: <http://www.ic.nhs.uk/statistics-and-data-collections/health-and-lifestyles-related-surveys/health-survey-for-england/health-survey-for-england--2009-trend-tables> [Accessed 10 April 2011]

Office for National Statistics (2011). Time Use Survey. Available from: <http://www.statistics.gov.uk/cci/nugget.asp?id=7>. [Accessed 31 May 2011]

Speiser, . W., Rudolf, M. C. J., Anhalt, H., Camacho-Hubner, C., Chiarelli, F., Eliakim, A., Freemark, M., Gruters, A., HersHKovitz, E., Iughetti, L., Krude, H., Latzer, Y., Lustig, R. H., Pescovitz, O. H., Pinhas-Hamiel, O., Rogol, A. D., Shalitin, S., Sultan, C., Stein, D., Vardi, P., Werther, G. A., Zadik, Z., Zuckerman-Levin, N. and Hochberg, Z. (2005). Consensus statement: childhood obesity. *The Journal of Clinical Endocrinology & Metabolism*, 90:3, 1871-1887.

Skender, M. L., Goodrick, G. K., Junco, D. J. D., Reeves, R. S., Darnell, L., Gotto, A. M. and Foreyt, J. P. (1996) Comparison of 2-year weight loss trends in behavioural treatments of obesity: diet, exercise, and combination interventions, *Journal of the American Dietetic Association*, 96 (4), 342-346.

Sterman, J. D. (2000), *Business dynamics: systems thinking and modelling for a complex world*. Boston, MA: Irwin McGraw-Hill.

Swinburn, B., Sacks, G. and Ravussin, E. (2009) Increased food energy supply is more than sufficient to explain the US epidemic of obesity. *American Journal of Clinical Nutrition*, 90, 1453-1456.

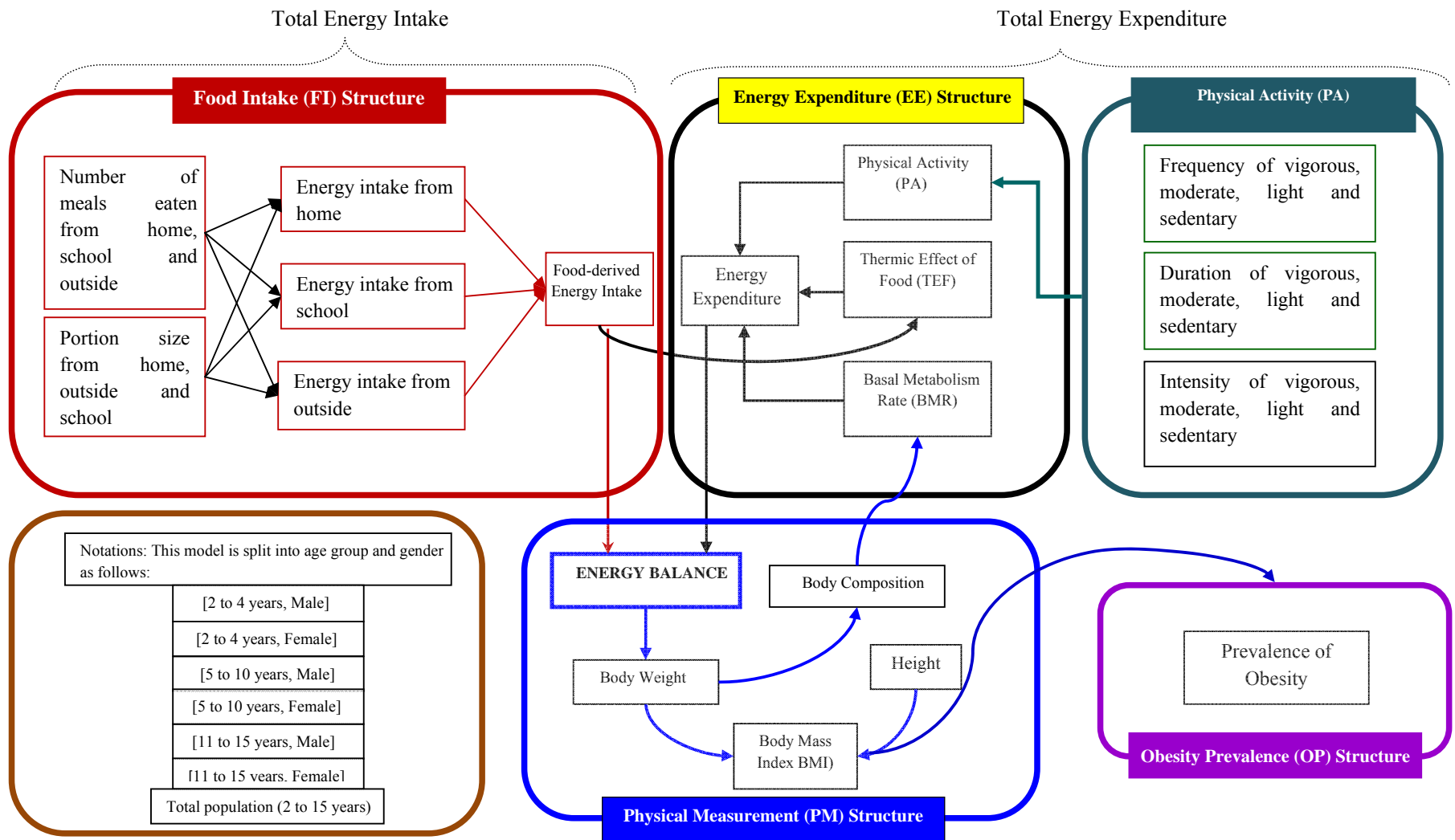
Taylor, K., Dangerfield, B. and Grand, J. L. (2005) Simulation analysis of the consequences of shifting the balance of health care: a system dynamics approach. *Journal of Health Services Research & Policy*, 10(4), 196-202.

Taylor, K. and Lane, D. (1998) Simulation applied to health services: some experiences so far and opportunities for applying the system dynamics approach. *Journal of Health Services*, 3(4), 226-232.

World Health Organization (WHO) (2011) Obesity and overweight. Facts about overweight and obesity Available from: (<http://www.who.int/mediacentre/factsheets/fs311/en/>). [Accessed on 20 May 2011].

Young, L. R. and Nestle, M. (2007) Portion sizes and obesity: responses of fast-food companies. *Journal of Public Health Policy*, 28, 238-248.

Young, L. R. and Nestle, M. (2002) The contribution of expanding portion sizes to the US obesity epidemic. *American Journal of Public Health*, 92 (2), 246-249.



APPENDIX: High-level map showing the dynamic hypothesis underlying the model of childhood obesity and energy balance