MODELING OF OBESITY EPIDEMICS BY INTELLIGENT AGENTS

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ABSTRACT

The paper focuses on a large scale problem related to population health care with special attention to obesity. The authors present a proposal for modeling human behavior and its influence on the evolution of obesity epidemics, and its effects on social networks, infrastructures and facilities. This approach is based on Intelligent Agents tools developed for reproducing country reconstruction and human factors. These models represents the base that allows to add specific and complex aspects related to pathologies and correlated behaviors that allows to reproduce these phenomena.

INTRODUCTION

Today one of the main problems is to adapt health care to the existing challenges in the society. This means that both public and private health care system have to face the problem to obtain and properly allocate resources for prevention, treatment and rehabilitation of a large assisted population with limited assets. In fact, these challenges are expected to grow in coming decades, due to a variety of reasons in different world regions: i.e. population growth, changes in life-span expectation, aging of the population, social and economic evolution. To solve this problem it is necessary to improve the effectiveness and efficiency in allocating the available resources.

Therefore, a better understanding of these complex phenomena affecting population health aspects is currently very critical to properly define health policies, actions and to plan future infrastructures and services to be able to face such challenges.

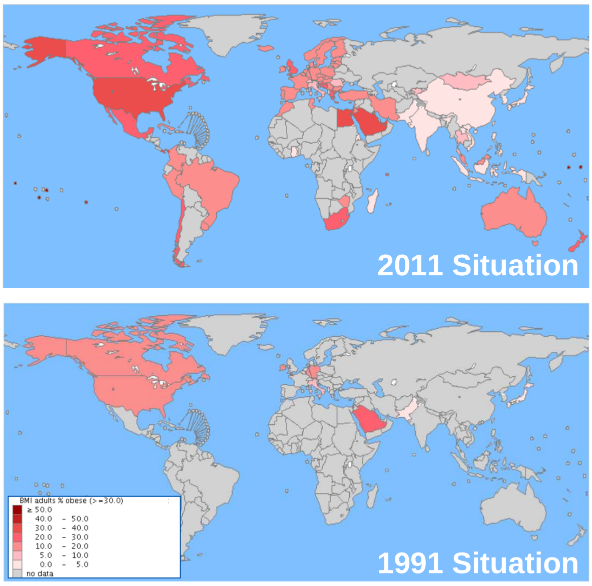

Figure 1. Obesity Epidemic evolution in last 20 years

It is evident that in health care more than in other sectors the high influence of stochastic factors and very complex correlation make difficult analysis on large scale without using modeling and simulation; so a very interesting aspect is obtain a better understanding of the phenomena generating/affecting current development of obesity epidemics that is dynamically and quickly evolving in many countries; and therefore, providing challenges today and threats for the future.

The authors propose to develop simulation models able to reproduce human behavior to address this problem and to provide support for decision makers; a first important benefit expected by these simulators should be the possibility to test and to validate the different existing hypotheses related to the mutual influence among different factors related to physiological and psychological issues, behavioral aspects and regional/ethnical/social/geographical and economical factors. In fact, by conducting experiments using information available in larger samples, it will allow us to validate the consistency of these predictions within a population over time and also across diverse populations..

Once the models become validated, it will be possible to use a forecasting system, that would allow to conduct risk analysis and estimation of future development; the simulator, used in this way, reproduces scenarios and generates forecasts in term of resources and facilities required for treatments, as well as estimation of the impact of costs and demand on the country infrastructures and industry. It would also allow to predicting the impact of behavioral, social and economic interventions to prevent further development of obesity epidemics and to curtail its costs.

Finally such simulators could become a very strategic advantage to support decision and to evaluate the impact of actions and countermeasures of public and private institutions and organizations on such a critical sector as the health care. The authors decided to start a joint research on these issues by focusing on obesity due to its strong impact on country economies and to its very complex and dynamic evolution (as proposed in figure 1, source World Health Organization Statistics Reports); in fact obesity of a population evolve based on individual and social behaviors over time (i.e. depression due to some social problems, lack of mobility, socially acceptable overeating etc.). The use of intelligent agents in this area represents an innovative opportunity for research; currently the authors present the first development on this track based on some available data and some adaptation of their simulation frameworks to this new context. It is expected that such research will be further developed in support of specific R&D programs.

THE OBESITY EPIDEMIC

The obesity epidemic (Wolf et al. 2007) has been increasingly spreading worldwide in the past three decades, involving even the countries that never in the past showed obesity among their population. The United States has observed of the highest rate of obesity increase in the world (Wang et al. 2007), affecting people of all ages including children, both genders, different ethnic and racial backgrounds, and various socioeconomic groups. Adult overweight and obesity are defined using body mass index (BMI): normal weight < 25; overweight: 25-29.9; obesity > 30

BMI Body Mass Index

$$BMI = \frac{W}{H^2}$$

W Weight [kg]

H Height [m]

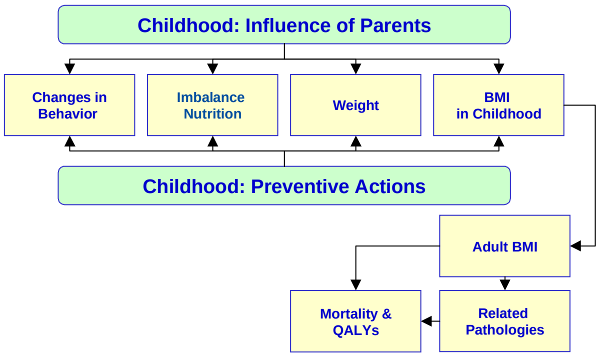

Figure 2. Basic Model of Obesity in Childhood

Children at risk for overweight are defined as the 85th and 95th percentiles of body mass index. Currently, (2010), no state has prevalence of obesity less than 20% and 26 states had a prevalence of 25% or more (Centers for Disease and prevention; www.cdc.gov); 66% of adults are overweight or obese; 16% of children and adolescents are overweight, and 34% are at risk of overweight. Minority and low-socioeconomic-status groups are disproportionately affected at all ages. By 2015, 75% of adults will be overweight or obese, and 41% will be obese.

Obesity is associated with increased risk of diabetes, hypertension, cardiovascular diseases, strokes and dementia, mobility dysfunction, cancer and mortality thus increasing significantly health care cost in the society.

Elevated body mass index is being increasingly recognized as a risk factor for stroke, cardiovascular disease, and cognitive decline (Falkstedt et. al. 2006; Cournot et. al. 2006). Diabetes epidemic follows obesity spread in the world, affecting countries that previous had a lower prevalence of diabetes.

It is expected that diabetes prevalence of people with diabetes will dramatically increase further between 2010 and 2030 i.e. India from 50.8 to 87 millions; China from 43.2 to 62.6;United States of America from 26.8 to 36.0;Pakistan from 7.1. to 13.6; Brazil from 7.6 to 12.7 (Wang et al. 2007).

A long-term population study with 27 years of the follow-up has shown prospectively that in the multiethnic population, midlife obesity increases the risk of dementia later in life.

Obese people (BMI ≥ 30) had a 74% increased risk of dementia (hazard ratio 1.74, 95% confidence interval 1.34 to 2.26), while overweight people (body mass index 25.0-29.9) had a 35% greater risk of dementia (1.35, 1.14 to 1.60) as compared with those of normal weight (body mass index 18.6-24.9) (Whitmer et al. 2005).

The increased risk for Alzheimer's disease and dementia later in life is independent even if adjusted for elevated blood pressure, smoking, socioeconomic status and genetic factors (Wolf et al.2007;Kivipelto et al.2005).

Obesity epidemic is associated with significant burden for the people, families and society and contributes significantly to increased health care cost, morbidity and mortality.
The exact cost of obesity to the society and people is not known.

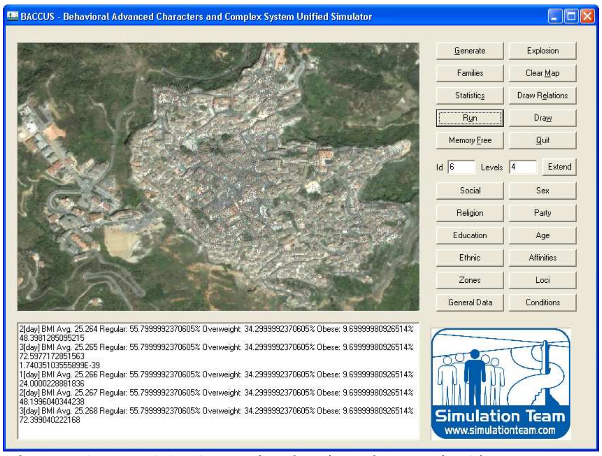

Figure 3. BACCUS: Behavioral Advanced Characters and Complex System Unified Simulator

However, a cost of diabetes could be used as an example; i.e. in 2010 -418 billions of international dollars, 8787 ID per person in the world and 55.7 billions of national income loss in China alone. It is expected that diabetes will increase death rates globally by 17% in 2030 and by 25-27% in Middle East, India and China (IDF Atlas 4th ed. International Federation on Diabetes). Therefore, health care cost will increase exponentially, as the obesity epidemics spreads into younger population and other countries.
Obesity is a multifactorial process that results from interactions among the individual health status, functional and social habits, social networks, education and other factors that cannot be predicted from a single variable (i.e. body mass) but requires nonlinear modeling of multiple variables and their interactions.
Although that reduced physical activity, increased food intake and social networking are commonly cited factors, the mechanism underlying obesity spread worldwide mechanisms remain poorly understood.
The mechanisms of obesity spread and their impact on the world's health, personal life and economy have not been well studied and therefore, the effective strategies to prevent obesity epidemics are lacking.

Impact of Obesity in Term of Costs

The social cost of obesity is related to several aspect (Cereda 2011); as first element it was demonstrated that in fact the obese individuals impact on national health care system costs exceed the average expenditure per capita of an individual's normal weight; therefore much of the social costs associated with obesity are due to different social interactions that obese individuals may have, always considered in comparison to a normal weight individual. A recent study in Australia has estimated the intangible costs arising from obesity in adulthood, reaching a value between 13 to 18 billion AU$; in addition to these aspects, many studies have proposed estimations of indirect costs of obesity highlighting the fact that their economic impact could exceed the direct health care costs, both in term of absolute and percentage of GDP (Magarey et al 2001).
For instance in the U.S.A., it is estimated a loss of production due to the obesity corresponding to 23 billion USD (1989-1990), while in Australia the loss for the country is estimated into 272 million AU$ (Australian Bureau of Statistics).
Recently some researchers have carried out a study with respect to the Chinese context, the analysis was derived from two reference years, 2000 and 2025 (Popkin et al 2006); based on these estimates it results, for the year 2000, an economic impact of 49 billion USD (4.06% of GDP), of which 43 billion dollars in indirect costs (3.58% of GDP). The magnitude of the economic impact is expected to reach a size even more critical, both for increased health spending and the consequences on the labor market. The projections to the year 2025 describe an expected total cost overpassing 112 billion USD representing 9.23% of GDP, of which 106 billion USD (8.73% of GDP) is attributable to indirect costs; these researches estimated that, even in China, the largest component of costs was represented by the loss of productivity due to absences due to illness, which causes 75% of indirect costs. The issues related to sickness, early retirement and disability, have been investigated in Sweden, Finland and Denmark (World Health Organization 1997).
The results produced have highlighted the link between increased BMI and sickness absence in the long term. Furthermore, considering the child obesity as a risk factor for obesity in adulthood, a fraction of the costs, direct and indirect, previously mentioned, the adult is generated from the high number of adolescents in which obesity has persisted over time. In this direction, some researchers have investigated the effects expected along the course of life resulting from a weight reduction program implemented in American schools.
It was introduced the parameter QALYs to quantify the results obtained: the QALY (Quality Adjusted Life Years acronym) is a unit of measure used in cost utility that combines the life span with the same quality. One QALY equal to 1 corresponds to the expected life of one year in normal health, the value 0 corresponds to death (Pliskin et al. 1980).
The measurement scale is continuous and a few years of life may also be given negative values (if you have serious conditions and acute suffering of immobility). QALY is used as an index weighting in the assessment of increases in life expectancy associated with health interventions.

Thus, for example, whether the introduction of a new surgical technique allows the patient to survive on average 6 years older, but the conditions are such that after the operation be considered equal to 0.2 QALY (eg., Because of serious motor deficiencies and frequent pain), the intervention effect on life quality will be weighted for only 1.2 years. Cost-utility analysis performed in the above studies was a cost of 4305 USD/patient per QALY gained, while the sum of the avoided health care costs and productivity losses avoided, you get an expected benefit, net of implementation costs of 7313 USD/patient for each program implemented (Wang et al.2003).

MODELLING THE PHENOMENA

The idea to reproduce the phenomena related to obesity is to use intelligent agent reproducing the population and let them evolve based on their behavior and on the applied actions and scenario evolution (Bruzzone et al.2011); the behavioral models are defined inside the agents, defined IA-CGF (Intelligent Agent Computer Generated Forces); for instance an high level example is proposed in figure 2; a combined stochastic simulation engine manage the interactions among the agents; this framework defined as NCF (Non Conventional Frameworks) could be tailored over very different contexts and areas. Previous researches have been carried out by Simulation team to develop models able to reproduce human behavior over town or regions (Bruzzone et al.2008); in fact these models were used originally for epidemic evolution (Avalle et al.1999), for analyzing urban disorders (Bruzzone et al.2006) and for country reconstruction (Bruzzone & Massei 2010).
In this case it was decided to create an ad hoc NCF with full inheritance of IA-CGF Libraries. For the specific research it was possible to start the development of new conceptual model and to design a first shell of NCF defined BACCUS (Behavioral Advanced Characters and Complex System Unified Simulator) that introduce several additional parameters related to physiology, health status and behavior; these parameters includes:

- BMI
- Sport Profile
- Alcohol Profile
- Stroke
- Infarct
- Diabetes
- Cancer
- Hypertension
- Atrial Fibrillation
- Hyperlipidemia

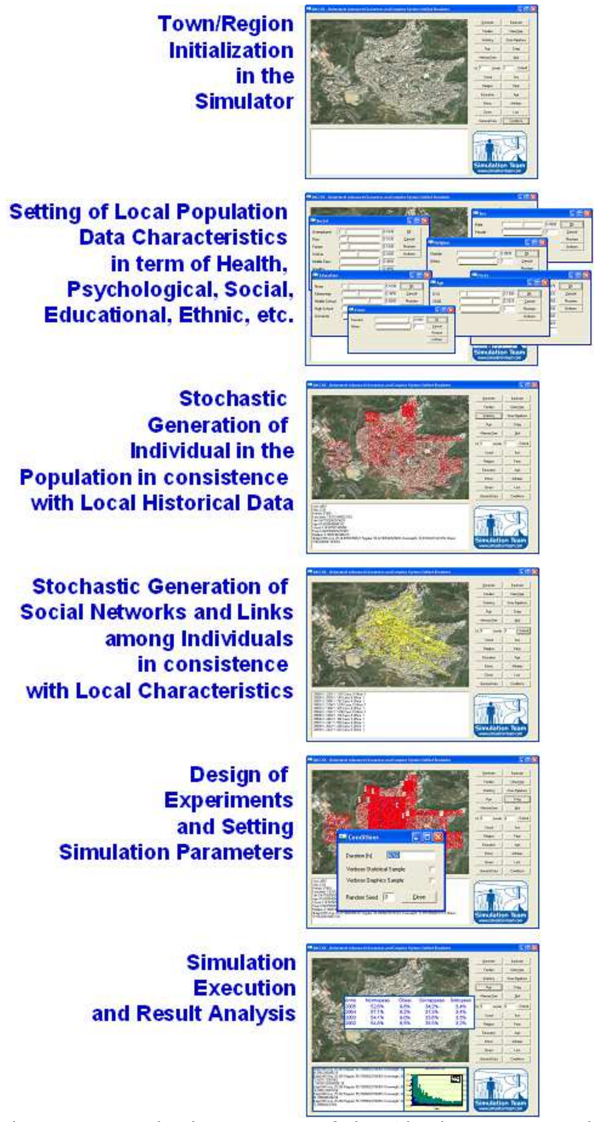

Figure 4. Investigation Process of the Obesity over a Region based on Modeling the Population Behavior

The BACCUS simulator is implemented using IA-CGF engine of the Simulation Team as anticipated and it is proposed in Figure 3. The development concept is based on a several step process; first phase is related to defining the population in term of PIG (people initialization groups); the PIGs represent the different groups present on a scenario; PIGs are defined in term of statistical distribution for their main factors (Social Level, Educational Level, Political Attitudes, Religion, Ethnic, Tribe, Gender, Age); based on these parameters the population is generated randomly respecting original statistics on the geographic region, but even considering the different groups characteristics with their specific structure (i.e. some ethnic group have different social status statistics respect other one living in the same region); this process generates the people agents; in addition inside the region it is possible to define Zones as objects that have affinities with the main factors and so the people agents are distributed geographically in term of living and working locations in consistency with their affinities; it is possible to overlap zones with different affinities in order to represent inconsistent mixes of different groups of the population. In addition to the individual aspects, in the model the aggregation parameters are defined to regulate the generation of social networks based on stochastic distributions; by Montecarlo technique the people agents are associated in term of families and working connection generating the social network; the behavior of each agent is defined by models that regulates how it operates under regular (i.e. working days, holidays) or special conditions (i.e. natural disasters, sickness period); an overall presentation of the procedure is proposed in Figure 4.

Table I: Extract of Results based on non parametric rank correlation on available samples

BMI	Age	-0,1937	0,0001*
BMI	Years of school	-0,0563	0,3876
BMI	Alcohol (Dose/Week)	-0,0543	0,3093
BMI	Glucose (mg/dL)	0,1265	0,0196*
BMI	Cholesterol (mg/dL)	-0,1278	0,0225*
BMI	Triglycerides (mg/dL)	0,2704	<,0001*
BMI	HDL (mg/dL)	-0,2944	<,0001*
BMI	Cholesterol/HDL Ratio	0,1610	0,0030*
BMI	LDL (mg/dL)	-0,1808	0,0010*
BMI	Hb A1C%	0,4136	<,0001*
BMI	HR BP BASELINE	0,1784	0,0133*
BMI	SBP BASELINE	0,0166	0,8176
BMI	DBP BASELINE	-0,0041	0,9544
BMI	Walk speed (m/s)	-0,3111	<,0001*

Table II: Some Correlation Extract among factors and BMI based on the available samples

	BMI
BMI	1,0000
Age	-0,2019
Years of school	-0,1108
Alcohol (Dose/Week)	0,0278
Glucose (mg/dL)	0,2203
Cholesterol (mg/dL)	-0,1334
Triglycerides (mg/dL)	0,1971
HDL (mg/dL)	-0,3103
Cholesterol/HDL Ratio	0,1540
LDL (mg/dL)	-0,1712
Hb A1C%	0,4041
HR BP BASELINE	0,1973
SBP BASELINE	0,0270
DBP BASELINE	0,0017
Walk speed (m/s)	-0,2725

Obviously dealing with human modeling the verification and validation of the simulator is critical as well as the data collection and analysis; for the preliminary test the hypotheses on the conceptual model relating behaviors with obesity was based on current researches (Christakis et al. 2007) as well on the analysis of data available in Beth Israel Deaconess Medical Center (BIDMC) in Boston and Harvard Medical School affiliate. In fact some general data used for simulation were derived from previous studies obtained by the databases of associations (i.e. World Health Organization, the American Heart Association and the American Diabetes Association).

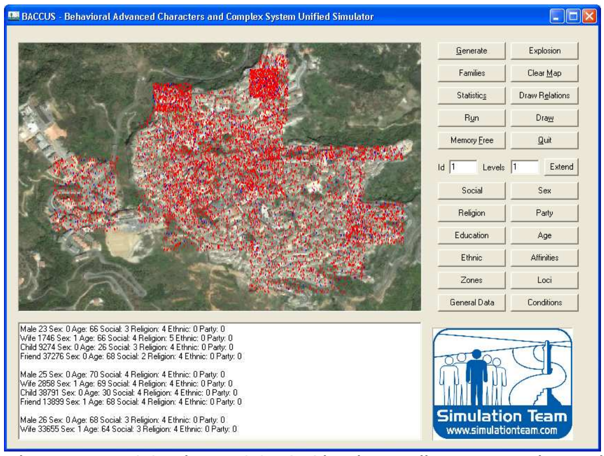

Figure 5. IA-CGF in BACCUS Simulator allows to evaluate the population behavior and its influence on the obesity evolution in the town

In addition it was used a sample related to 170 subjects in the Syncope and Falls in the Elderly Laboratory (Lab SAFE), active in the BIDMC; these 170 patients in the sample was volunteers, aged between 50 and 85 years, recruited from the SAFE Lab for four samples, conducted in the years 2006 to 2010.

All four samples considered issues related to diabetes; in fact the data were related to studies correlating diabetes with other pathologies, so the sample includes other diseases such as patients with myocardial infarction or stroke.

All samples have a quite balanced ratio between balance between male patients and female patients.

There are some limitations in using samples of existing populations that were collected or originated for different studies, and therefore do not provided sufficient information i.e. about frequency of measurements, include specific populations, or have missing values for certain parameters.

Therefore, this paper represents a first step forward for modeling and tuning simulators for investigating obesity, so the focus is mostly on creating the conceptual models, introducing consistent data and tuning the parameters in order to obtain reasonable results by the simulation runs.

Some examples, of the parameters used to check mutual influences are reported in table I e II; statistical analysis and ranking methodologies was applied in order to check data significance and their correlation.

The low level of correlation obtained was expected due to the reason above mentioned; therefore the analysis was useful to identify procedures and aspects to be investigated in future data collections and researches.

In order to proceed it was decided to implement some behavioral model and correlation algorithms among the factors based on author's hypotheses consistent with the data available.

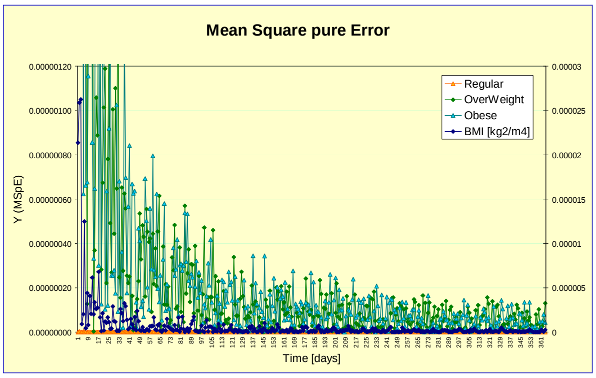

Figure 6. BACCUS VV&A based on Dynamic Analysis of Mean Square pure Error on Population Obesity Classes

The scenario used to the tests was a small town of about 15'000 inhabitants; target functions included the population sharing among the different obesity classes and the average BMI:

- Regular
- Overweight
- Obese
- Average BMI

In figure 5 it is proposed the BACCUS during execution of the proposed scenario, analyzing each single individual. The VV&A (Verification, Validation & Accreditation) of BACCUS is based analysis of MSpE (Mean Square pure analysis) as measure of the variance of the target functions among replicated runs over the same boundary conditions; by this approach it becomes possible to identify the number of replications and the simulation duration able to guarantee a desired level of precision; MSpE values in correspondence of these experimental parameters determines the amplitude of the related confidence band:

$$MSpE^m(t,n_0)=\frac{\sum_{i=1}^{n_0}\left[Sr_i^{\ m}(t)-\frac{1}{n_0}\sum_{j=1}^{n_0}Sr_j^{\ m}(t)\right]^2}{n_0}$$

$$CBA^m(t,n_0,\alpha)=\pm t_{\alpha,n_0}\sqrt{MSpE^m(t,n_0)}$$

t	simulation time
m	m-th target function estimated by the simulator
no	number of replications with same boundary conditions and different random seeds
$Srk^m_k(t)$	m-th target function value at t time of the k-th replicated simulation
$MspE^m(t,n_o,\alpha)$	Mean Square pure Error at t time and with no replications for the m-th target function
α	percentile
$CBA^m(t,n_o,\alpha)$	Confidence Band Amplitude at t time, with no Replications for the m-th target function

In fact the MSpE allows to quantify the experimental error due to influence of the stochastic components; as presented in figure 6 the variance of all the target function reach steady state situation over a reasonable number of replications and over a time horizon of about 1 year. so this confirm that simulator provides consistent results on a stable situation with capability to define the confidence band for estimating the obesity target functions.

CONCLUSIONS

The use of agents and simulation to investigate large scale health care problems represent an important opportunity; obviously in these case it is critical to guarantee a multidisciplinary approach to the problem; in fact from this point of view the authors represents a good example of different skills and background with common interest.

The obesity epidemic represents a very important and interesting application framework that could be very useful to consolidate research in this area of M&S related to Medicine and Health Care.

The research highlighted the critical aspects related to collecting, mining and filtering the data to define the conceptual models related to such complex problems as well as to support parameter fine tuning and simulator VV&A. The model and the present results in this first phase are promising and the potential of using Intelligent Agents in this context is very great considering the impact of the obesity epidemic.

This presentation represents the first step on this research track, and currently the authors are working on some experimental analysis in term of impact on different industries (i.e. beverage and airlines) as well as in the further development of the models and their validation using datasets of a larger , longitudinal cohorts of diverse populations in different countries.

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