MOTIVATION PROBLEMS IN THE PROCESS OF MASS REDUCTION THROUGH MODELLING AND SIMULATION

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ABSTRACT
An important observation is the fact that overweight and obesity (obesity being in 1997 by World Health Organization recognised as a chronic disease which has to be healed) have reached epidemic extensions and represent an important social and economic burden for the countries as well as for many individuals. They also represent a risk factor for developing several chronic diseases and consequently serious health complications. In the paper a description organization is presented enabling the coexistence of different models indicating several problem levels and so giving the estimation of overweight and obese population, connections with other diseases or risk factors and estimation of economic burden as well as the possible consequences of healing interventions. Special attention is devoted to the efficacy of open and close – loop weight control at the level of individual patient and the potential consequences to the observed population.

Keywords: obesity, motivation problems, modelling, control design

1. INTRODUCTION AND MOTIVATION

Unhealthy life style very frequently consists of inactivity, stress, improper and/or too rich or abundant food resulting in a number of problems among which the first one is usually overweight.

A simple index of weight-for-height (known as body mass index - BMI) is commonly used in classifying overweight and obesity in adult population. It is defined as the weight in kilograms divided by the square of the height in meters (kg/m^2). It provides rough but very useful measure of overweight and obesity as is the same for both sexes and for all ages of adults (WHO 2011). It is important to mention that now-days physicians pay attention also to waist circumference but this parameter was not taken into account during this study because of the lack of statistical data.

Regarding WHO (WHO 2011) overweight is defined as a BMI equal to or more than 25, and obesity as a BMI equal to or more than 30. Children were defined as overweight or obese using the 85^{th} and 95^{th} percentiles of the reference curves. WHO's latest estimations indicate that globally in 2008 approximately 1.5 billion adults (age 20+) were overweight (WHO 2011).

It is important to point out that overweight and obesity are not the problem only by itself (lower immune system, more difficult movement, not very high self-esteem, social isolation, …), but they lead also to serious health consequences. Risk increases progressively as BMI increases. Raised body mass index is a major risk factor for chronic diseases such as diabetes type 2 (MMWR 2004; Daousi et al. 2006; Atanasijević-Kunc et al. 2008b; Atanasijević-Kunc and Drinovec 2011), hyper- and dislipidemia and hypertension (Atanasijević-Kunc et al. 2008b), but can evolve also to serious cardiovascular disease (Atanasijević-Kunc et al. 2008b; 2011), musculoskeletal disorders (Corbeil et al. 2001), and some cancers (WHO 2011; Atanasijević-Kunc et al. 2008a).

These conditions have also a significant social consequences and economic impact on the health care systems (Atanasijević-Kunc et al. 2012).

Obesity was in 1997 by World Health Organization recognized as a chronic disease. It is very difficult to be treated successfully in spite of the fact that the main energy equilibrium laws are known in great details (Hall 2010; Navarro-Barrientosa et al. 2011).

The goals of the paper are:

- to review in short some of the modelling approaches when analysing the problems connected with overweight and obesity,
- to present the modelling structure which enables the coexistence of different models which can share the simulation results to present different view-points of the problem,
- and to introduce the description of motivation problems which can help in understanding of patient's behaviour through the process of mass reduction.

2. MODELLING OBESITY

As has been indicated in the previous section, obesity is a multi-dimensional problem. It is dangerous and as such important for each individual patient. It has to be treated. It represents an important risk factor for a great number of other diseases. Because of epidemic extensions this chronic disease has become also an economic burden which can't be neglected.

All these important facts have stimulated the development of models and concepts concerning the problems with increased body mass. They all contribute to better problem understanding, enable problem analysis and represent a step toward a reduction of this burden. Models can be, similar to other modelling problems from the field of medicine, pharmacy and life sciences (Hoppensteadt and Peskin 2002; Stahl 2008; Atanasijević-Kunc et al. 2008a; Belič 2009; Arnold 2010; Atanasijević-Kunc and Drinovec, 2011), divided regarding very different criteria. Some of them are:

- ***the level of problem observation***
  some of the models describe the problems from the perspective of the whole observed population or specific group of patients (Santonja et al. 2010; Kovács et al 2011; Atanasijević-Kunc et al. 2012), even more frequent are presentations at the level of individual patient (Abdel-Hamid 2002; Hall 2010; Navarro-Barrientosa 2011), sometimes changed mechanical properties are observed (Corbeil et al. 2001), but the problems can be described also at the level of chemical reactions (Abdel-Hamid 2002);
- ***connections with other diseases, risk factors or processes***
  are also frequently indicated (Navarro-Barrientosa 2011; Atanasijević-Kunc et al. 2012), while in some cases authors focus only to overweight and obesity control(Hall 2010);
- ***treatment, treatment policy, treatment efficacy, economic burden of treatment, economic efficacy***
  here again the processes can be observed from the view-point of each individual, while sometimes also wider situation is taken into account, like health - care system or even global social and economic environment (Atanasijević-Kunc et al. 2012);
- ***psychological and behavioural problem interpretations***
  are reaching more and more attention as treatment efficacy is still essentially under desired level (Navarro-Barrientosa 2011);
- ***static or dynamic, problem description***
  when static descriptions are used statistical properties are frequently presented for problem interpretation (Landi, et al. 2010), while dynamical models (Abdel-Hamid 2002; Hall 2010; Navarro-Barrientosa 2011) enable also the observation of different transient responses; in such cases time is frequently used as independent variable, but sometimes also patients' age is chosen to be independent variable in problem description (Atanasijević-Kunc et al. 2012);
- ***continuous or discrete problem description***
- ***open and/or closed – loop problem interpretation***
  where also dynamic changes of closed – loop operation can be of great interest (Kovács et al. 2011);
- ***other possible criteria***
  which can be taken into account are qualitative models, agent based models, expert system, …;

Regarding the diversity of used modelling approaches and corresponding goals it seems interesting to develop the structure with which it would be possible to illustrate the burden of epidemic extensions of obesity at the level of observed population and corresponding economic consequences and main relations with risk factors, other diseases and processes. In addition it is important to enable the study of problem minimization and its efficacy.

The proposed structure is presented in Fig. 1. It consists of different levels which indicate problem observation from the population perspective. Here only main direct flows are indicated while in some situations also feedback loops can be expected.

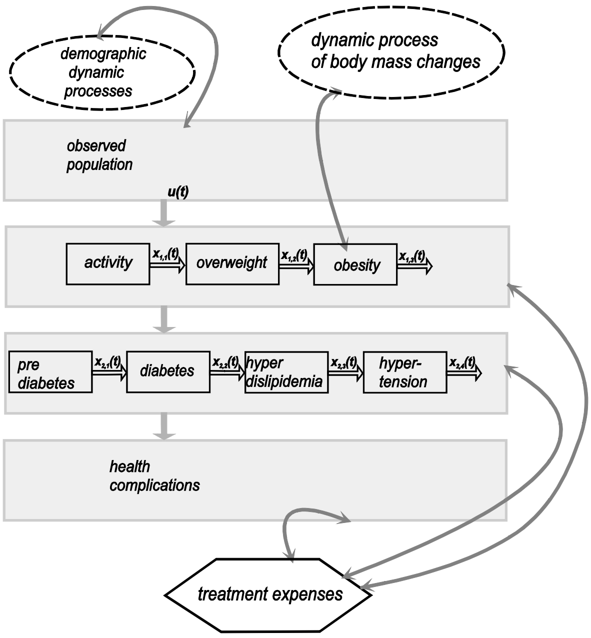

Figure 1: Diseases development in the population

In addition also some other important dynamical processes or modelling results of complementary models can be combined with the results of the main structure.

Resembling modelling structures (like in Santonja 2010) usually describe the whole population separated into compartments, taking into account the incidence or prevalence of developing diseases or disease stages (like: normal, overweight, obese, extreme obese). Each compartment is represented as homogeneous entity where age of the patients from the observed group or compartment is not of prime importance. These groups are observed through time (months or years) regarding body mass changes.

We have decided to observe the indicated groups of patients in such a way that also age of patients can be interpreted as an independent variable. The reason for this decision is the fact that development of chronic diseases depends strongly also on patients' age.

At the first level of the proposed structure the whole observed population is taken into account. The input signal to the second level is a unity step indicating the observation start time that is at birth. At the next level the processes which are defining life style are taken into account. Among them is, as an exception, also obesity as one of the earliest chronic diseases. In the third level the most frequent chronic diseases are indicated, starting with the pre-diabetes, which can sometimes be regarded as a curable disease. At the fourth level serious health complications are taken into account. Each of indicated diseases is described with the prevalence response regarding patients' age through the whole life time. Each of presented blocks in Fig. 1 is described with dynamic model which transforms input signals to outputs, calculating patients' prevalence distributions of indicated disease. They were identified using available statistical data for each disease and for diseases' combinations.

This representation can therefore be understood as an extension of decision tree formalism (Atanasijević-Kunc and Drinovec, 2011) which is frequently used in pharmacoeconomical studies (Arnold, 2010; Stahl, 2008). In contrast to classical decision tree (which is a static problem description) proposed representation comprises, as mentioned, also a time component.

Another advantage of this structure is that it indicates some of process properties and gives the possibility of simple results combination with demographic data to evaluate the number of observed people or patients as will be illustrated in the next section. This information can further be combined with treatment expenses and so also economic burden can be estimated.

Treatment interventions in overweight and obese patients usually start with the observation of energy inbalance. In spite of the fact that rather good model predictions for body mass reduction are available (Abdel-Hamid 2002; Hall 2010; Navarro-Barrientosa 2011) the prevalence of overweight and obesity is very high. The question is why, because the great majority of these patients would like to lose few kilograms. A very simple answer (which needs additional study) is that also in the cases where the way of problem solution is completely clear it is not simple to be realized. Some interesting facts which prove this situation are the following.

A great effort invested in losing weight is often ineffective, sometimes even harmful (Abdel-Hamid 2002). After years of little change, sales of diet pills and supplements have more than quadrupled since 1996, but the prevalence and incidence of obesity is still increasing. Products like:

- slimming soaps that slough off fat in the shower,
- miracle pills that get rid of excess pounds without dieting or exercise,
- plastic earplugs that curb the appetite,
- and even a glittering ring called Fat-Be-Gone that when slipped on a finger trims hips, buttocks and thighs

are of great interest?!?

Among US adults participating in programs for losing or maintaining weight, only 17.5% were following recommended guidelines for reducing calories and increasing physical activity (Navarro-Barrientosa et al. 2011).

Obviously very strong processes are influencing patient's behaviour during mass reduction treatment. One of our goals is to present through modelling and simulation at least some of them. This can help in understanding and designing efficient mass reduction programs.

3. SIMULATION RESULTS

3.1. Social burden at the population level

To illustrate the burden of obesity and some of related processes at the population level let's choose to observe Austria as an example of developed EU country. Social burden is indicated through the number of obese patients.

In Fig. 2 the number of people regarding their age (Statistik Austria 2012) is illustrated together with developed model predictions for the next 50 years. Model is using average statistical data regarding fertility, mortality and migrations from 2006 to 2010. Fertility was calculated regarding the number of people in the age window from 18 to 45. It was estimated that each year 2.32% newborns are expected regarding the mentioned group of people. In 2010 the largest group of people was old approximately 45 years while in 2060 the maximum can be expected around the 70s. The population is becoming older also in this country. The number of newborns is expected to decrease for 30% through the next 50 years resulting in reduction of the whole population for 13%.

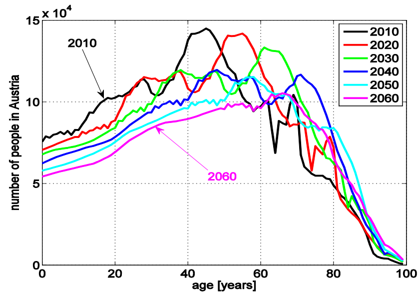

Figure 2: Population prediction from 2010 to 2060 in Austria

As indicated in Fig. 1 an important risk factor for developing obesity represents inactivity (Brock et al 2009). To the group of active people are most often classified those, who are active 30 minutes or more on at least five days a week (BHFSW 2012a). Usually activity in men and women slightly differ, but the average prevalence model response is illustrated in Fig. 3 (Atanasijević-Kunc et al. 2012).

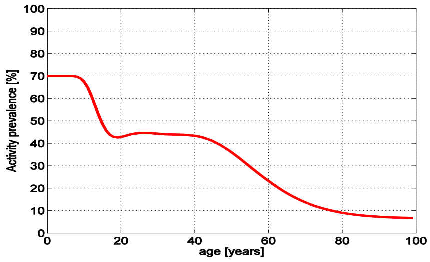

Figure 3: Prevalence of activity

Combination of this result with the number of people in Austria (Fig. 2) enables the calculation of the number of active people (see Fig. 4).

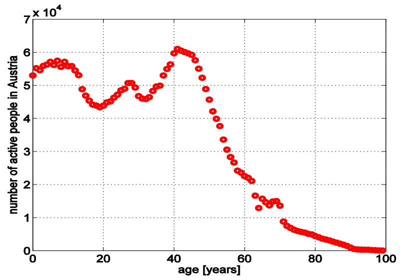

Figure 4: Number of active people in Austria (3 200 000 or 38%)

The prevalence of obesity differs from country to country and is also different regarding men and women (Berghöfer et al. 2008). Obesity is developed from those who are overweight. The ratio between both groups changes slightly with patients' age but was estimated in average to be: overweight/obese = 1.3, and therefore for both group of patients only one model was developed (BHFSW 2012b; Atanasijević-Kunc et al. 2012). Model responses describing average prevalence are illustrated in Fig. 5 and in Fig. 6 where also those who are active and those who are not can be observed.

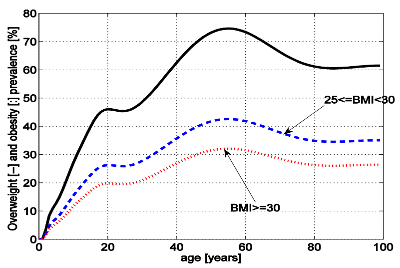

Figure 5: Prevalence of overweight and obese population and the sum of both groups

Combination of these results with population number show that in Austria over 4.4 million people have BMI greater than 25, or with other words 55% are overweight or obese.

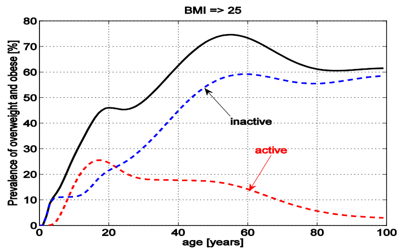

Figure 6: Prevalence of overweight and obese active and inactive population

Both, inactivity and obesity are very important regarding the development of diabetes type 2 (D2) (Valensi et al. 2005). It was discovered that most adults (up to 90%) with diagnosed diabetes were overweight or obese (MMWR, 2004), 52% were obese, and 8.1% had morbid obesity (Daousi 2006).

Before D2 is fully developed patients have a pre-diabetes which in general significantly differs from D2 regarding the fact that when strict life change is adopted taking into account corresponding diet and activity, sometimes complemented by corresponding drug treatment, patients can return to normal condition. Sometimes this transition is (for example due to a long lasting pre-diabetes) not possible, but in such situations D2 development is in most cases significantly postponed. Pre-diabetes is not a true disease but can be interpreted as a serious risk factor for developing D2 and cardiovascular diseases. Over 30% of people with pre-diabetes develop D2 within five years (Valensi et al. 2005). The average conversion rate was estimated at 5.8% per year with wide variations which depend on differences in age, BMI, ethnicity, etc.. It is very important to accent that several well-designed randomized controlled trials (Valensi et al. 2005) have been reported that categorically confirm the benefits of interventions in the pre-diabetes. Standardized diet with reduced food intake, increased physical activity and sometimes also additional drug treatment can reduce the incidence of D2 for almost 60% (in mentioned studies from 25% to 58%). But, it is important to point out that the intensive lifestyle modification was nearly twice as effective in preventing D2. It is therefore evident that an active management of pre-diabetes can be very effective in preventing the progression of diabetes.

Model responses presenting average prevalence distribution of pre-D2 and D2 are illustrated in Fig. 7, while in Fig. 8 number of D2 patients are shown and among them also those who have BMI>25. In Austria 31% of population are pre-D2 patients, while 7.8% have D2.

3.2. Economic burden

Practically all who have unhealthy body mass (BMI>25) would like to lose their weight. At least 40 % from the age window of 18 to 60 are experimenting with the drugs which are available without the medical prescription. 30% of people from the same age window are using drugs, prescribed by physician (20%- sibutramin; 80%- orlistat). 80% of patients with BMI>40 need also anti-depressive treatment (fluoxetin). In addition the expenses are needed for these patients due to examination and laboratory.

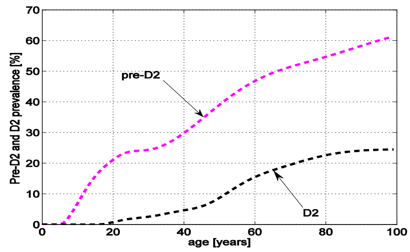

Figure 7: Prevalence of pre-D2 and D2

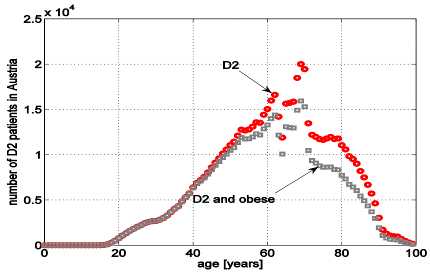

Figure 8: Number of patients with D2 in Austria

It was estimated (Atanasijević-Kunc et al. 2012) that in Austria around €330 per patient is spend each year for direct treatment expenses, while approximately the same amount is needed also for the indirect expenses. Regarding a population of one million people this represents an economic burden of over €360 million each year.

When observing Fig. 9, where the number of D2 patients is illustrated for 2010 and prediction for 2060, it can be expected that the burden of obesity will become even more concerning, as the ratio between working and retired people is decreasing, while at the same time the number of D2 patients is increasing.

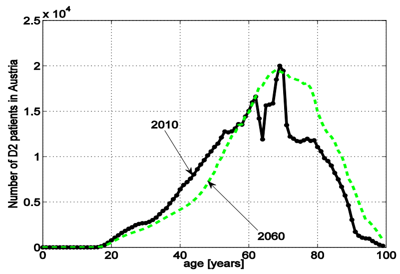

Figure 9: Number of patients with D2 in Austria in 2010 and in 2060

From this it is clear that decrease of obese and overweight population would represent an essential increase of life quality for many individuals. In addition it would save a lot of money needed for drugs, medical services and interventions. Straightforward problem solution is therefore body mass reduction.

3.3. Dynamical process of body mass reduction

For quantification of the problem solution several mathematical models are available. In this case we have used the three - compartment model (Chow and Hall 2008; Navarro-Barrientosa et al. 2011) for an average person. Model enables to differ among fat-free body mass (*ffm*) and fat mass (*fm*), where *ffm* is represented as a sum of lean mass (*lm*) and extra cellular fluid (*ecf*). Equation for daily energy balance is:

$$EB(t) = EI(t) - EE(t) \qquad (1)$$

where *EI(t)* represents daily energy intake and *EE(t)* daily energy expenditure. Energy intake depends on food and its caloric value:

$$EI(t) = k_1 ci(t) + k_2 fi(t) + k_3 pi(t) \qquad (2)$$

ci(t) indicating carbohydrate intake, *fi(t)* fat intake and *pi(t)* protein intake, and constants k_i are: k_1=4*kcal/gram*, k_2=9*kcal/gram*, k_3=4 *kcal/gram*. It is recommended that protein intake represents 20-30%, fat intake 15-20% and carbohydrate intake 55-60% daily intake of the food. Daily energy expenditure is calculated as follows:

$$EE(t) = tef(t) + PA(t) + rmr(t) \qquad (3)$$

where *tef(t)* is thermic effect of feeding which usually ranges from 7 to 15% of the total energy intake (11% in our case), *PA(t)* represents energy spent on physical activity and *rmr(t)* is the so called resting metabolic rate. It refers to the energy needed to maintain basic physiological processes. It represents a substantial percentage (45-70%) of energy expenditure for the typical individual. The daily energy balance *EB(t)* is partitioned into one of three compartments:

$$\frac{dfm(t)}{dt} = \frac{(1-p(t))EB(t)}{\rho_{fm}} \qquad (4)$$

$$\frac{dlm(t)}{dt} = \frac{p(t)EB(t)}{\rho_{lm}} \qquad (5)$$

$$\frac{decf(t)}{dt} = \frac{\rho_w}{K}\left(\mathrm{B} - \xi_{Na}\left(ecf(t) - ecf_{init}\right) - \xi_{Cl}\left(1 - \frac{ci}{ci_b}\right)\right) \qquad (6)$$

where ρ_{lm}= ρ_{fm}=1800 kcal/kg, *B* is the change of sodium in mg/d, ci_b is the baseline carbohydrate intake, *K*=3.22mg/ml, ξ_{Na}=3 mg/ml/d, ξ_{Cl}=4000 mg/d, ρ_w= 1kg/l.

$$p(t) = \frac{C}{C + fm(t)}, \qquad C = 10.4\frac{\rho_{lm}}{\rho_{fm}} \qquad (7)$$

Daily energy expenditure can be expressed explicitly as:

$$EE(t) = \beta EI(t) + \delta BM(t) + D +$$
$$+\gamma_{lm} lm(t) + \gamma_{fm} fm(t) + \eta_{fm}\frac{dfm(t)}{dt} + \eta_{lm}\frac{dlm(t)}{dt} \qquad (8)$$

where β=0.24 (coefficient of thermic effect of feeding), δ is physical activity coefficient, γ_{lm}=22 kcal/kg/d, γ_{fm}=3.2 kcal/kg/d, η_{lm}=320 kcal/kg, η_{fm}=180 kcal/kg, while constant *D* accounts for initial conditions.

In our case an average person (between men and women) was taken into account. From his-hers average height (1.72m regarding 11 European countries) and average BMI=32 also the average mass of this person was estimated to be 94.6688kg. Regarding medical recommendations such person should lose around 30kg to satisfy BMI=22 in the middle of desired BMI interval. The initial fat mass was estimated from the regression equations (Jackson 2002): $fm(0)$=34.7 kg.

Simulation result is illustrated in Fig. 10, where the vertical lines indicate the years of observation while the horizontal lines indicate desired range of BMI. Through the first year energy balance is in equilibrium and body mass is not changing. After the first year physical activity is increased for 210 kcal per day what can be realized with 45 minutes of walk. Such increased energy expenditure results after two years in desired BMI. If this person is able to continue with such life modification he-she reaches recommended steady state.

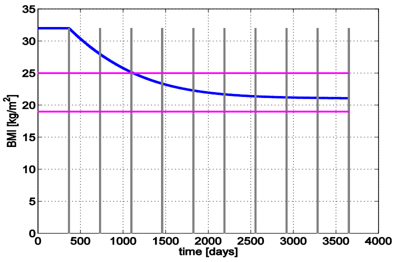

Figure 10: Lowering BMI in average obese person with increased activity (45 minutes of walk)

Let's take into account the following assumptions. 80% of obese and inactive people age 20 and older are motivated to undertake the presented regime of increased activity. With this they are immediately transferred into the group of active population, where they remain. After two years of activity they are also transferred out from overweight and obese population and they remain in the group of people with healthy body mass (Figs. 11 and 12).

Figure 11: Increase of the number of active patients with BMI>25

The reduction of obese population would of course first decrease direct expenses due to obesity and later on also indirect expenses because of reduced number of the patients with D2 and other diseases. Expected decrease of D2-patients through longer transient is illustrated in Fig. 13.

Figure 12: Decrease of the number of patients with BMI>25

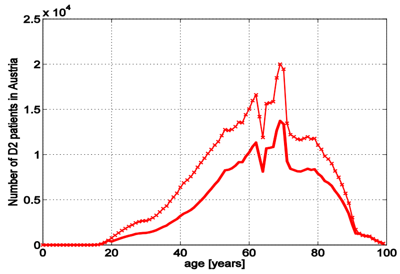

Figure 13: Decrease of D2 patients

3.4. Treatment efficacy analysis

In spite of the fact that treatment could, at least theoretically, be realized in most cases without any expenses (as proved with simulation experiment), mainly with increased activity (or/and moderate decrease of food energy intake) which is anyway recommended for the healthy life style, the result is far from ideal and is actually expected to become even worse (WHO 2011). The problem is obviously far more complicated and is in practice a very demanding one even in the situations when experts are involved to help in corresponding treatment.

First attempts of deeper problem understanding and treatment were realized by psychiatrists Bruch (1948) and Stunkard (1959). They have realized that around 98% of patients regain undesired body mass. Now-days the efforts are directed mainly in problem prevention and in implementation of programs which would enable efficient and long – term treatment (O'Rahilly and Farooqi 2008; Karasu and Karasu 2010; Hall and Jordan 2008; Sentočnik, 2012).

It is important to take into account, that reasons for obesity are numerous and patients represent very inhomogeneous group. Patients with higher BMI are more difficult to be treated successfully.

Mass reduction usually starts with self – treatment experiments, next stage is performed regarding the advices of family doctor, sometimes also personal trainers are engaged. If the results are not satisfying more intensive programs are available at basic health – care system. Treatment is intensified and personalized at sanatoriums where specialists with the help of multidisciplinary team perform integral treatment. Final stage, that is surgical help, is usually suggested when other possibilities proved to be insufficient.

Successfulness of mass reduction is very often evaluated regarding long – term weight stabilization and the reduction of risk factors of chronic diseases (Sentočnik 2012). In successful patients the need for drug treatment is frequently omitted.

3.4.1. Open – loop treatment approach

As already mentioned the treatment efficacy in obese patients is in general not very high and the main reasons are different problems which influence patients' behaviour in such a way that they are unable to follow the recommended guidelines for reducing calories and/or increasing physical activity.

It seems therefore very important to complement energy equilibrium description with the model of behavioural interventions which would indicate the most important treatment interventions. Navarro-Barrientosa et al. (2011) suggested the usage of the so called theory of planned behaviour, which was extended to dynamic interpretation with interesting analogy in hydraulic system interpretation. It is however not very clear how to influence directly the parameters like attitude, subjective norm and intention to reach desired level of behaviour.

Regarding the results of long research work in sanatorium Medico dr. Sentočnik one of the most important and transparent factor influencing the patient's behaviour habits is the frequency of realized treatments. Patients are usually invited (after starting detailed examination and developed plan of interventions) to come regularly each week to the sanatorium where the prescribed corresponding treatment is performed (including physical activity, psychological treatment, …). It is very important that the patient realizes these treatments regularly. If treatments are postponed or omitted the efficacy of treatment is always essentially decreased.

We have decided to describe this observation through the level of motivation which has the range from 0 to 100%. If the patient is 100% motivated, he-she completely realizes the prescribed intervention, when motivation is 0% this means his-hers eating/activity pattern remains the same as before the treatment. The level of motivation is influencing prescribed activity and energy intake. It can be expected that during one year of regular treatment motivation becomes strong enough so that patient is able to master new habits by him(her)self. The idea is illustrated in Figs. 14 to 18.

For this experiment previously mentioned three – compartment model of average obese person was used. In Fig. 14 motivation is illustrated. Each time when he-she realizes weekly treatment, motivation is increased to 100%. Between these weekly treatments motivation is decreasing, but with the increased number of visits the lowering is less intensive.

In Fig. 15 energy intake is presented. It was taken into account that the patient should decrease the energy intake to 1900 kcal per day, which represents the day reduction of 560 kcal which is in harmony with medical directions for the obese persons. In Fig. 15 energy intake is oscillating as a result of motivation influence.

Energy expenditure (Fig. 17) is decreasing because of mass reduction, which is illustrated in Fig. 18. When the desired body mass is reached energy intake can be increased to the value of new energy equilibrium.

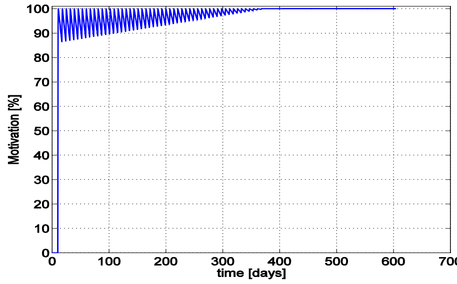

Figure 14: Motivation in patient with regular treatment

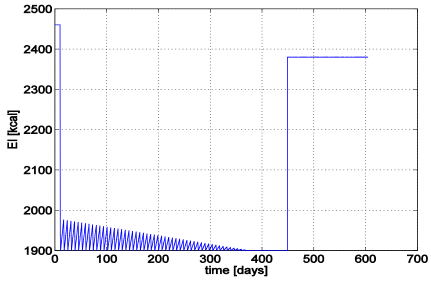

Figure 15: Energy intake in patient with regular treatment

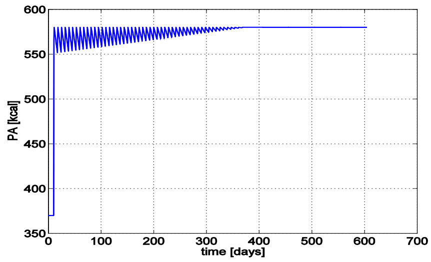

Figure 16: Physical activity in patient with regular treatment

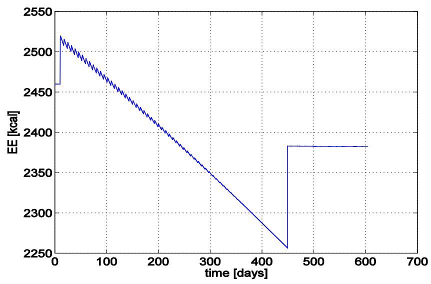

Figure 17: Energy expenditure in patient with regular treatment

The second experiment illustrates the situation where the patient is realizing the treatments regularly for two month. Then he-she feels he has become strong enough to finish the treatment by him(her)self. But in this case it can be expected that motivation starts to drop and reaches the starting position in next two months (Fig. 19). This further influences energy intake

(Fig. 20), physical activity (Fig. 21), and energy expenditure (Fig. 21).

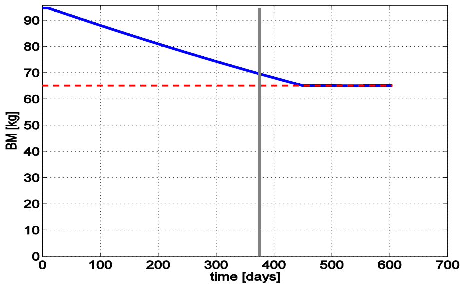

Figure 18: Body mass in patient with regular treatment

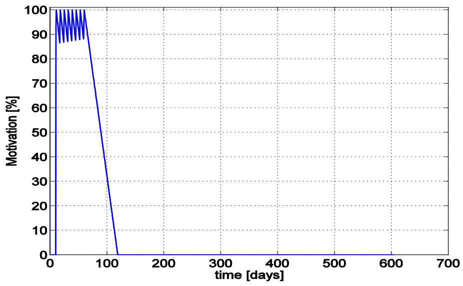

Figure 19: Motivation in patient with unregular treatment

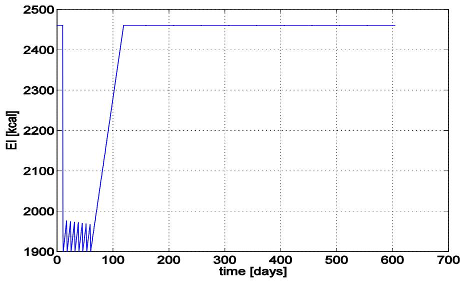

Figure 20: Energy intake in patient with unregular treatment

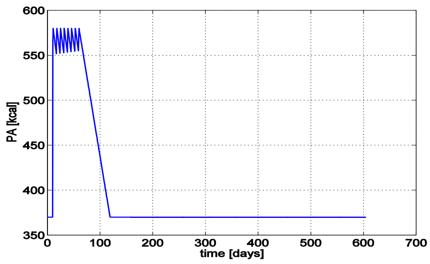

Figure 21: Physical activity in patient with unregular treatment

Body mass of the patient is in this case far from desired value (Fig. 23).

As interventions are in this case pre-defined and remain unchanged during treatment regarding body mass, this treatment can be interpreted as open loop.

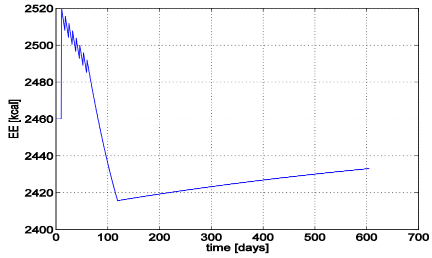

Figure 22: Energy expenditure in patient with unregular treatment

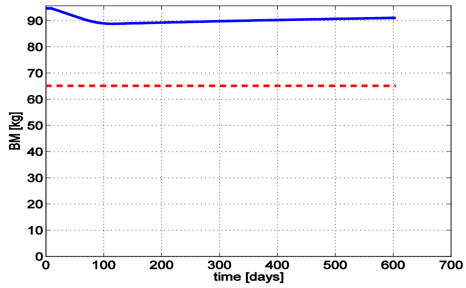

Figure 23: Body mass in patient with unregular treatment

3.4.2. Closed – loop treatment approach

Medical specialists usually carefully supervise patient's progress and health status and can of course react if the process of mass reduction is not satisfactory. This situation is illustrated in Figs. 24 to 28.

In Fig. 24 desired (reference) and actual body mass reduction is illustrated for the situation when the patient regularly realizes prescribed weekly treatments.

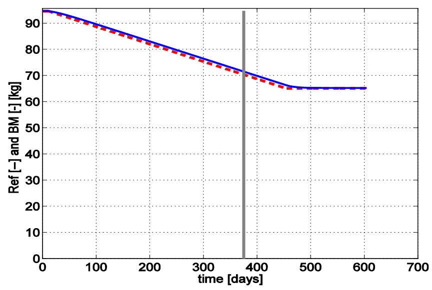

Figure 24: Reference body mass and body mass (solid line) in patient with regular closed-loop treatment

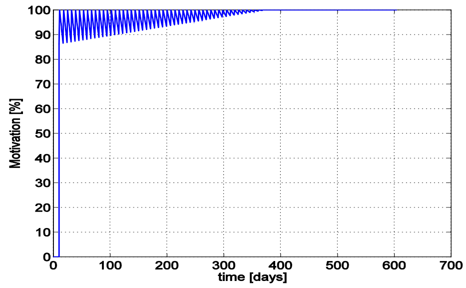

Figure 25: Motivation in patient with regular closed-loop treatment

Motivation is as a consequence high enough and also energy intake (Fig. 26), physical activity (Fig. 27), and energy expenditure (Fig. 27) are correspondingly maintained using proportional controller.

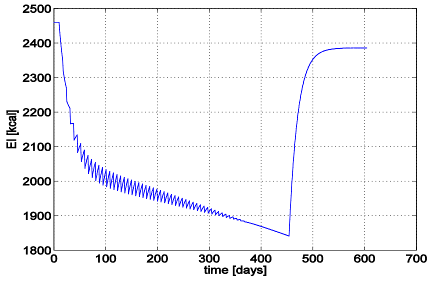

Figure 26: Energy intake in patient with regular closed-loop treatment

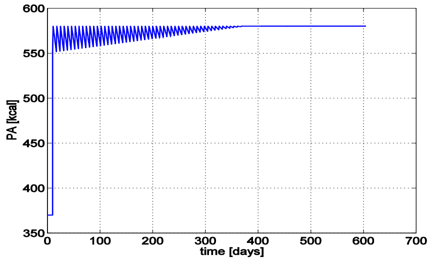

Figure 27: Physical activity in patient with regular closed-loop treatment

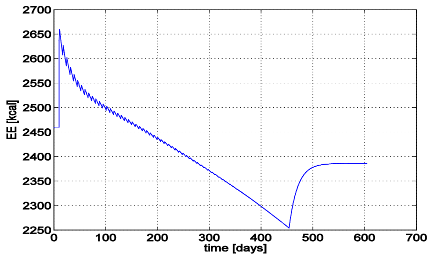

Figure 28: Energy expenditure in patient with regular closed-loop treatment

In the case when the patient stops with regular treatment, feedback loop is disconnected and control action is disabled. The result becomes in this case very similar to those indicated in Figs. 19 to 23.

It is important to mention that the presented model is still far from the final version and is in this case illustrated only for an average person.

In the future further tuning will be performed taking into account also the matching with the real patient data. It can be expected that also control law needs further development where also the behavior of medical specialists can play an important role.

4. CONCLUSIONS

In the paper a description organization is presented enabling the coexistence of different models indicating different problems connected with overweight and obesity. When observing an European country, like for example Austria, it can be expected that around 55% of population has BMI>25 or higher as recommended. In the population of one million people for these patients each year around € 360 million is needed. It can be expected that this burden will increase in the future because of population ageing.

For efficient treatment long – term weight stabilization should be achieved which demands also long – life change of life style for all overweight and obese patients. This is a tremendous practical problem. In the paper the steps through modelling results are indicated which base also on a very long research in sanatorium Medico dr. Sentočnik.

The model needs further improvement and that will be our future research goal.

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