WEIGHT LOSS THROUGH DIET & EXERCISE: A SIMULATION STUDY

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I. INTRODUCTION

According to 2015-2016 CDC data, the prevalence of obesity in the United States was 39.8% and affected about 93.3 million US adults. Obesity-related conditions include heart-disease, stroke, type 2 diabetes and certain types of cancer that are some of the leading causes of preventable, premature death. According to Duke University health economist ,Eric Finkelstein, the estimated annual medical cost of obesity in the United States was $147 billion in 2008 US dollars; the medical cost for people who have obesity was $1,429 higher than those of normal weight.

In 1990, obese adults made up less than 15 percent of the population in most U.S. states. By 2010, 36 states had obesity rates of 25 percent or higher, 12 of those having obesity rates of 30 percent or higher. Today, nationwide, roughly two out of three U.S. adults are either overweight or obese (69 percent). It is clear that obesity has become an overwhelming issue affecting the United States.

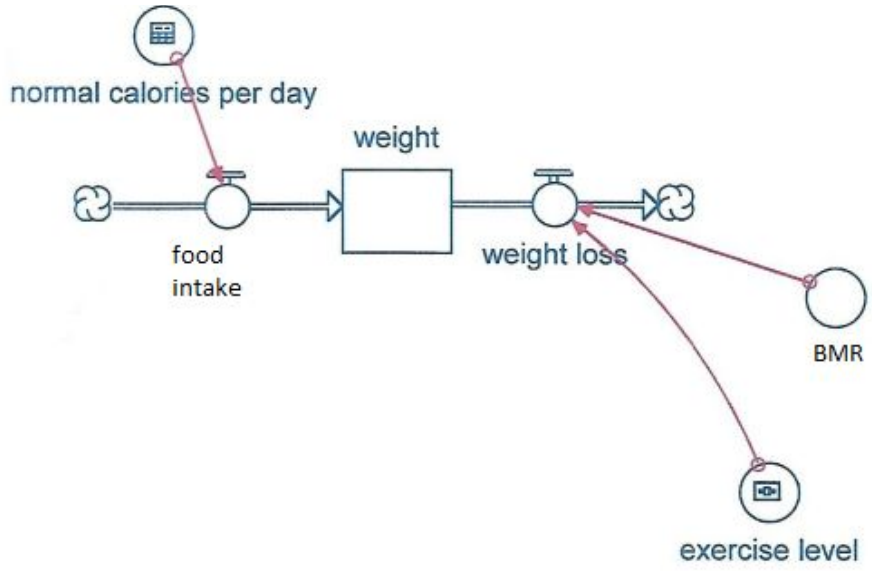
I believe that one of the reasons why obesity has become such a big issue is because of the lack of knowledge on the best ways to stay fit and the best ways to prevent obesity, through both diet and exercise. The purpose of my study is to give people an easy way compare various levels of diet and exercise to see the effect it would have on their body over a period of time. This would allows users of this information to decide on a diet and exercise plan that works for them and helps them reach their goals. This model will be able to provide those want to lose weight and better their health by giving them the information they need to get started. This model can also be used by those who are lost on trying to figure out how much they should eat each day in order to maintain their weight, lose, or gain weight by breaking down the number of calories they should be eating each day as per their lifestyle.

By building a model of the situation, I am able to conduct a study that simulates each diet and exercise plan instantly. Therefore, providing the necessary information one needs to proceed on their journey to health. It prevents the need to try out various diets and exercises in order to determine which one makes a person lose weight at their ideal rate. Thus, saving the person a ton of time and energy.

II. BACKGROUND

System Description:

The system that I created in order to model a weight change over time is a continuous system in which calculations are done each time step in order to determine the weight change during that time step. In this model, each time step represents 1 day. In that one day the model uses the user-provided data to calculate how much weight in pounds, the user would lose according to the preferred caloric deficit.



The diagram above illustrates the system configuration of my simulation. It is based off of Raymond Madachy's models of a similar system.

We can see that the input of the simulation is the food intake that person eats on a usual day. This amount of calories is based on the normal calories per day that person should eat depending on their diet and whether they want to lose weight. This input is what regulates the weight of the individual. There is also an output to this weight. This output is the weight loss rate of the person. This is determined by the exercise level of the person and the basal metabolic rate of that person (BMR). The BMR is the number of calories a person burns each day just to maintain basic life functions such as digestion, respiration, organ function, and muscle maintenance. It is a measure of the exact number of calories you need each day, without considering your lifestyle activity level of the calories you burn during exercise. The weight loss is also determined by the exercise level of the person. The more exercise the person does in a day, the more calories they will burn. Therefore, the more calories they burn, the more weight they will lose; that is if they are eating the same amount of food as someone else who does not exercise. In order for a person to lose weight, they need the number of

“calories out” to be greater than the number of “calories in”. The number of calories in is easy to determine. It is just the total amount of calories that a person intakes through food in a given day, that is the total number of calories a person eats or drinks each day. Calories out is the total number of calories burned according the a person’s basal metabolic rate, combined with the total number of calories burned through exercise each day. The difference between calories in and calories out (calories in - calories out) = daily calorie deficit. In order to determine the total calorie deficit we have to take in the amount of calories taken in through food and subtract the amount of calories burned from working out and the amount of calories burned from the RMR. The daily caloric deficit is what can be used in order to determine one’s weight loss. A normal caloric deficit for weight loss ranges anywhere from 5% on the low end to 25% on the higher end.

III. MODEL DEVELOPMENT

Modeling Approach:

In order to create this model, I had to decide what would be the most useful information to provide someone with who is looking to use this simulation in order to determine a weight loss strategy. My first thought was to compare and contrast various popular diets (ketogenic diet, paleolithic diet, vegan diet) over a certain period of time. However, the way weight loss works it doesn't matter which diet you go on as long as you are eating at a caloric deficit. Therefore, since the diet doesn't matter I decided that I wouldn't integrate these various diets into the model and instead would only take into account the caloric deficit. This also makes a much simpler model as it would be very difficult a person's weight loss journey when taking into account proteins, carbohydrates, and fats and the effect that those have on the body.

Once I decided on the information that I was going to use as the basis of the model (calories), I needed to determine how to measure a person's "calories in" and "calories out" and the effect that a caloric deficit has. After much research I determined that calories in is simple, it is just the sum of all the calories that a person eats in a day. Calories out is a little more difficult as it takes in to account one's basal metabolic rate, as well as the calories they burn from exercise. Therefore all I have to do is model the calories in - calories out equation continuously each day, keeping track of the caloric deficit and determining how that affects one's weight. According to the Mayo Clinic, 1lb of fat is equivalent to about 3,500 calories. This gives me the information I need to determine exactly how the caloric deficit affects body weight. In order to determine the amount of weight a person loses each day, you can take their caloric deficit of the day (calories in - calories out) and divide that number by 3,500 to convert the calories into pounds. Therefore doing this calculation each day can be used to model weight loss over time.

Problems:

In my initial model, the weight loss of the person was completely linear, however I knew that this did not accurately reflect real life weight loss. This is because in my initial model I calculated the basal metabolic rate of the person once at the beginning of the model and used this initial number for each daily calculation to determine the total calories burned. However, the reason why this isn't accurate is because the equation for the basal metabolic rate (see section IV) includes the person's weight as a parameter, therefore a person's metabolic rate fluctuates with their change in weight. Using this information I modified my model so that each day the basal metabolic rate of the person is recalculated in order to more accurately reflect that person's weight loss over time.

IV. MODEL DESCRIPTION

Time frame:

The time frame of the simulation is variable. The user of the simulation can choose how long they want to track the weight changes for. The user enters the number of months they would like the model to simulate. A recommended number of months is from 1-3 as the model is most accurate for this time frame.

Entities:

User of the model or the person who is looking to lose weight.

Attributes:

All of the attributes of the person looking to model a weight loss are their age (years), height (inches), gender (male or female), weight (pounds), exercise level (1-5), caloric deficit (%). These attributes are used to calculate the BMR (basal metabolic rate).

Key Assumptions:

One assumption for this model is that it is used by people that are overweight or obese and are attempting to use it in order to determine what plan they need to follow in order to lose weight. It may work for people who are attempting to gain weight, but it is not designed that way so there may be errors in that case. Another assumption is that the model's time frame isn't longer than a few months as it will be less accurate late in the model if it the time frame is set longer than that.

Sequence of events:

In order for the simulation to start, the user enters their body information including their age, gender, height, weight, exercise level, caloric deficit they would like to model, and the amount of time they would like to mode it for. These numbers are used to determine the person's initial basal metabolic rate (BMR), you can see the equation for the BMR below. For example, a 30 year old male that is 6 feet tall and 180 pounds will have a BMR of 1,897 calories. Then the model takes into account the exercise level entered. The corresponding multiplier (see equation below) is used with the BMR to determine the total amount of calories burned for that person. For example, a exercise level of "2" corresponds to being lightly active which means that person does light exercise or sports 1-3 days a week. Therefore that persons total calories out is 2,609 calories. This means that if that person eats 2,609 calories each day and keeps exercising at that level they will stay at the exact same weight. The model then takes the percent caloric deficit added at the beginning and applies that to the calculated calories in, modifying it in order how much the person must eat in order to lose weight corresponding to that

caloric deficit. In this case if the man wanted to eat at a caloric deficit of 10%, this would mean that he would have to eat 260 less calories per day (2,348 total calories). The model then calculates the change in weight over the chosen period of time in months. The results show how much weight the person would lose if they followed the proposed routine. Lastly the model determines how much weight the person lost per week and compares it to the healthy maximum amount of weight to lose per week (1-2 lbs.) in order to determine whether or not this model is safe to follow. In this example the man would lose an average if 0.51 pounds per week, which according to the model, is a safe amount.

Equations:

Converting calories to fat loss:

```
1 lb. of fat = 3,500 calories
```

Basal Metabolic Rate (BMR):

```
Men: BMR = 66 + (6.23 x weight in pounds) + (12.7 x height in inches) - (6.8 x age in years)

Women: BMR = 655 + (4.35 x weight in pounds) + (4.7 x height in inches) - (4.7 x age in years)
```

Harris Benedict Formula:

To determine the total daily caloric need, multiply the BMR by the appropriate activity factor, as follows:

- **If you are sedentary (little or no exercise) : Calorie-Calculation = BMR x 1.2**
- **If you are lightly active (light exercise/sports 1-3 days/week) : Calorie-Calculation = BMR x 1.375**
- **If you are moderately active (moderate exercise/sports 3-5 days/week) : Calorie-Calculation = BMR x 1.55**
- **If you are very active (hard exercise/sports 6-7 days a week) : Calorie-Calculation = BMR x 1.725**
- **If you are extra active (very hard exercise/sports & physical job or 2x training) : Calorie-Calculation = BMR x 1.9**

Code:

Below is the Python 3 code that is used to run the model. The only external library necessary to run the model is matplotlib which is a python 2D plotting library used by the model to create a graph showing the change in weight over time.

The model can also be run at:

https://repl.it/@tmartinson/Diet-and-Exercise-Model

```
import matplotlib.pyplot as plot

timepoints = []
wpoints = []

dt = 1 # timestep

# initialization
time = 0
dw = 0

age = float(input("Please enter your age:"))
gender = input("Please enter your gender (m,f):")
height = float(input("Please enter your height (inches):"))
weight = float(input("Please enter your weight (lbs):"))

exerciseLevel = int(input("\nPlease enter the level of exercise you would like to
model (1-5)\n1. sedentary (little or no exercise)\n2. lightly active (light
exercise/sports 1-3 days/week)\n3. moderately active (moderate exercise/sports 3-5
days/week)\n4. very active (hard exercise/sports 6-7 days a week)\n5. extra active
(very hard exercise/sports & physical job or 2x training)\n:"))

deficitPercent = float(input("Please enter the % caloric deficit you would like to
model:"))

totalTime = 30 * int(input("Please enter how many months you would like to model
this diet for:"))

# Basal Metabolic Rate Calculation
# Men: BMR = 66 + (6.23 x weight in pounds) + (12.7 x height in inches) - (6.8 x age
in years)
# Women: BMR = 655 + (4.35 x weight in pounds) + (4.7 x height in inches) - (4.7 x
age in years)

BMR = 0
if (gender == 'm'):
    BMR = 66 + (6.23*weight) + (12.7*height) - (6.8*age)
else:
    BMR = 655 + (4.35*weight) + (4.7*height) - (4.7*age)

print("\n\nYour Basal Metabolic Rate (BMR) is:",int(BMR),"calories")

# Calculate BMR and Exercise Total
```

```
if (exerciseLevel == 1):
    BMR = BMR*1.2
elif(exerciseLevel == 2):
    BMR = BMR*1.375
elif(exerciseLevel == 3):
    BMR = BMR*1.55
elif(exerciseLevel == 4):
    BMR = BMR*1.725
else:
    BMR = BMR*1.9

print("Your BMR + calories burned from exercise is:",int(BMR),"calories" )
print("This is the amount of calories you should be eating each day to stay at your
same weight.")

# Caloric Deficit Calculations
deficit = deficitPercent/100
print("Eating at a",deficitPercent,"% caloric deficit would mean
eating",int(BMR*deficit),"less calories per day.")
print("Therefore, you would be eating,",(int)(BMR-BMR*deficit),"calories per day.")
print("This is what your change in weight would look like over time.")

# Calculating actual weight change
# 3500 calories = 1 lb of fat
netCalsLost = BMR*deficit
netWeightLost = netCalsLost/3500

# print output header and starting values
print ("   \nTime   Weight   Change(lb) Change(cals)")
print ("%6.2f  %6.2f   %6.3f       %6.2f" % (time, weight, dw, 0.00))

# time loop
while time < totalTime: # run for alloted time
    # total caloric deficit = amount of calories taken in through food and
    # subtract the amount of calories burned from working out and the amount
    # of calories burned from the RMR.
    # caloric deficit = food - (workoutCals + BMRCals)
    # 3500 calories = 1 lb of fat

    # compute derivatives
  #-------------------------------------------------
  if (gender == 'm'):
    BMR = 66 + (6.23*weight) + (12.7*height) - (6.8*age)
  else:
    BMR = 655 + (4.35*weight) + (4.7*height) - (4.7*age)

  if (exerciseLevel == 1):
    BMR = BMR*1.2
  elif(exerciseLevel == 2):
    BMR = BMR*1.375
  elif(exerciseLevel == 3):
    BMR = BMR*1.55
  elif(exerciseLevel == 4):
```

```
    BMR = BMR*1.725
  else:
    BMR = BMR*1.9
  netCalsLost = BMR*deficit
  netWeightLost = netCalsLost/3500
  #-----------------------------------------------------
  # increment time
  time += dt # time = time+ dt
  # update troop state variables
  dw = -netWeightLost  # x attrition rate
  weight += dw # calculate new weight


  if(weight<0): # edge case to prevent errors
    weight = 0
    break # stop looping

  print ("%6.2f  %6.2f   %6.3f      %6.2f" % (time, weight, dw, -netCalsLost))
  wpoints.append(weight)
  timepoints.append(time)

print("\nA healthy amount of week to lose per week is about 1-2 pounds.")
print("According to this model, you would lose about%6.2f lbs per week." %(dw*-7))

plot.xlabel('Time (days)')
plot.ylabel('Weight (lb)')
plot.plot(timepoints,wpoints)
plot.show()
plot.savefig('output.png')
```

Example:

Below is an example input and output of the program. It shows how the user interaction with the program works and shows the output of the example.

Input:

```
Please enter your age:25

Please enter your gender (m,f):m

Please enter your height (inches):70

Please enter your weight (lbs):200

Please enter the level of exercise you would like to model (1-5)
1. sedentary (little or no exercise)
2. lightly active (light exercise/sports 1-3 days/week)
3. moderately active (moderate exercise/sports 3-5 days/week)
4. very active (hard exercise/sports 6-7 days a week)
5. extra active (very hard exercise/sports & physical job or 2x training):3
```

```
Please enter the % caloric deficit you would like to model:20

Please enter how many months you would like to model this diet for:2
```

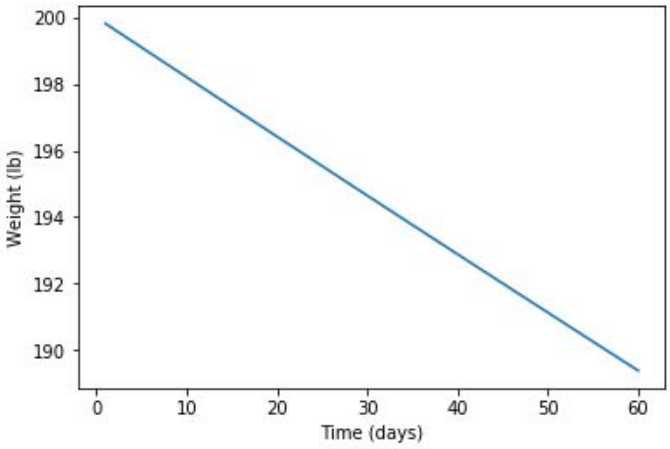
Output:

```
Your Basal Metabolic Rate (BMR) is: 2031 calories
Your BMR + calories burned from exercise is: 3148 calories
This is the amount of calories you should be eating each day to stay at your same
weight.
Eating at a 20.0 % caloric deficit would mean eating 629 less calories per day.
Therefore, you would be eating, 2518 calories per day.
This is what your change in weight would look like over time.

Time  Weight Change(lb) Change(cals)
0.00  200.00  0.000      0.00
1.00  199.82 -0.180     -629.61
2.00  199.64 -0.180     -629.26
3.00  199.46 -0.180     -628.92
4.00  199.28 -0.180     -628.57
5.00  199.10 -0.179     -628.22
6.00  198.92 -0.179     -627.87
7.00  198.74 -0.179     -627.53
8.00  198.56 -0.179     -627.18
9.00  198.38 -0.179     -626.84
10.00 198.21 -0.179     -626.49
11.00 198.03 -0.179     -626.14
12.00 197.85 -0.179     -625.80
13.00 197.67 -0.179     -625.45
14.00 197.49 -0.179     -625.11
15.00 197.31 -0.179     -624.76
16.00 197.13 -0.178     -624.42
17.00 196.96 -0.178     -624.07
18.00 196.78 -0.178     -623.73
19.00 196.60 -0.178     -623.39
20.00 196.42 -0.178     -623.04
21.00 196.24 -0.178     -622.70
22.00 196.07 -0.178     -622.35
23.00 195.89 -0.178     -622.01
24.00 195.71 -0.178     -621.67
25.00 195.53 -0.178     -621.32
26.00 195.36 -0.177     -620.98
27.00 195.18 -0.177     -620.64
28.00 195.00 -0.177     -620.30
29.00 194.82 -0.177     -619.95
30.00 194.65 -0.177     -619.61
31.00 194.47 -0.177     -619.27
32.00 194.29 -0.177     -618.93
33.00 194.12 -0.177     -618.59
34.00 193.94 -0.177     -618.25
35.00 193.76 -0.177     -617.90
36.00 193.59 -0.176     -617.56
37.00 193.41 -0.176     -617.22
```

```
38.00 193.23 -0.176     -616.88
39.00 193.06 -0.176     -616.54
40.00 192.88 -0.176     -616.20
41.00 192.71 -0.176     -615.86
42.00 192.53 -0.176     -615.52
43.00 192.35 -0.176     -615.18
44.00 192.18 -0.176     -614.84
45.00 192.00 -0.176     -614.50
46.00 191.83 -0.175     -614.16
47.00 191.65 -0.175     -613.83
48.00 191.48 -0.175     -613.49
49.00 191.30 -0.175     -613.15
50.00 191.13 -0.175     -612.81
51.00 190.95 -0.175     -612.47
52.00 190.78 -0.175     -612.13
53.00 190.60 -0.175     -611.80
54.00 190.43 -0.175     -611.46
55.00 190.25 -0.175     -611.12
56.00 190.08 -0.175     -610.78
57.00 189.90 -0.174     -610.45
58.00 189.73 -0.174     -610.11
59.00 189.55 -0.174     -609.77
60.00 189.38 -0.174     -609.44

A healthy amount of week to lose per week is about 1-2 pounds.
According to this model, you would lose about 1.22 lbs per week.
```



As we can see, the model outputs a table that displays the day, current weight, weight loss in pounds as well as total caloric change. Then it gives a message determining whether or not this weight loss model would be safe to follow in real life. Lastly it displays a graph to give an easy visual representation of the weight change over time. As you can see it looks very linear but if you look at the data the weight loss rate does slow over time, this is due to the change in weight affecting the person's BMR.

V. MODEL VERIFICATION AND VALIDATION

The results of the model can be tested against known data of similar experiments. For example, the results can be compared to before and after information for people's weight loss journeys. One place to find information on this is on www.reddit.com/r/fitness , a site in which many people share personal information on their weight loss journeys, including their workouts, the amount of food they ate each day, the caloric deficit that they stayed at, and their weight change over time.

I came across information about one person's weight loss journey that they shared on this forum. All of the weight loss information was given anonymously, but all the information I need to verify my model is there. Below is the information given in the post:

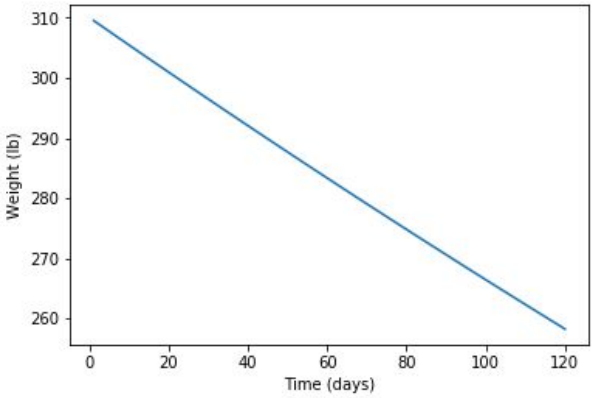
Starting weight: 310
Current weight: 250
Height: 6' 4"
Age: 22
Caloric deficit: 30% (person's best estimate)
Length of time: 4 months
Exercise: 4-6 days a week

I took all of this information and plugged it into my model to see what it would give in terms of weight change. Below is the output.

```
Your Basal Metabolic Rate (BMR) is: 2812 calories
Your BMR + calories burned from exercise is: 5344 calories
This is the amount of calories you should be eating each day to stay at your same weight.
Eating at a 30.0 % caloric deficit would mean eating 1603 less calories per day.
Therefore, you would be eating, 3741 calories per day.
This is what your change in weight would look like over time.

Time Weight Change(lb) Change(cals)
0.00 310.00 0.000 0.00
1.00 309.54 -0.458 -1603.35
2.00 309.08 -0.458 -1601.73
3.00 308.63 -0.457 -1600.10
4.00 308.17 -0.457 -1598.48
5.00 307.71 -0.456 -1596.86
...
116.00 259.84 -0.408 -1426.69
117.00 259.44 -0.407 -1425.24
118.00 259.03 -0.407 -1423.80
119.00 258.62 -0.406 -1422.35
120.00 258.22 -0.406 -1420.91
```

A healthy amount of week to lose per week is about 1-2 pounds.According to this model, you would lose about 2.84 lbs per week.



Looking at the output of the model, it determined that the person's estimated weight after four months would be 258.22 lbs. Comparing that to the person's actual weight after four months of 250 lbs. That is a percent error of only 3.3%. See calculation below.

$$\frac{|E-T|}{|T|} \times 100$$

$$= \frac{(258.22-250)}{|250|} \times 100$$

$$= \frac{8.22}{250} \times 100$$

$$= 0.03288 \times 100$$

$$= 3.288\%$$

$$= 3.288\% \text{ error}$$

It was difficult to find many other sources of data to compare my model to that had all the information necessary. Therefore, while this data points toward a valid model, I can't validate it based on this data alone.

VI. MODEL APPLICATION AND TRANSITION

Analysis of results:

After the simulation is finished, both a table and a graph are created to show the change in weight over time as well as the calculated caloric deficit for each time step in the continuous simulation. These data plots can be looked at to determine the rate of change. The outputs of various different inputs can be compared to each other in order for the user to determine which combination of exercise level and caloric deficit levels give the results that they person is looking for over the specified period of time.

Limitations:

One limitation of the model is that the model will always calculate the same percent of caloric deficit each day which is extremely difficult to replicate in real life. This is because when people calculate how many calories they eat in a day, it is impossible to get a perfect measurement. It is also not always feasible for someone to eat the correct amount of calories every single day as they may not have a choice of another meal or aren't able to measure each meal. It is also very likely that in real-life the person will not be able to meet the number of exercises perfectly due to a number of reasons: vacation, weather, sickness ,etc. Therefore it must be known that the model has a % error which has to be taken into account when looking at the validity of the model. Therefore this model can be used as a guideline for a lifestyle change and can be followed perfectly if possible, but most likely won't be able to follows without being a little off. It's also possible that because of people's different health conditions, diseases, or illnesses as well as the fluctuations in one's metabolism that each person's experience applying the model may be different. It will be more accurate for some and less accurate for others, however overall it is a good tool to use as an outline for a weight loss journey.

Future enhancements:

A future enhancement to this model that would be extremely useful would be if every single meal could be tracked. This could include the type of food eaten as well as the type of nutrients, i.e. proteins, carbohydrates, or fats. If this was included, the model could give greater insight into the ideal percentages of your caloric intake that should come from proteins, carbohydrates, and fats. This would be extremely hard to create as the model would need a near infinite level of data on each and every source of food and their nutrients. However if a massive database of nutrient information is available to the model, various meals could be planned out by the simulation in order to give an even more detailed outline of the weight loss plan.

Another possible future enhancement is a more advanced workout and exercise planning section. This would make it so that the model could suggest various workout routines and could be less vague on the level of exercise. Therefore, the model would be able to track

the amount of calories burned even more accurately as well as track each workout in order to change the intensity overtime so that each workout became increasingly harder, thus training the user to become more in shape over time.

VII. CONCLUSIONS AND RECOMMENDATIONS

Real-word application:

There are a few different real-world applications for this model. I believe that it could be modified into a mobile or web application as a quick, easy tool for people to use and play around with in order to provide them with the information they need in order to start a weight loss journey. It would give a short, concise answer to the questions that they may have about how to go about their weight loss and would leave out all of the extra, unnecessary information that is all over the internet about ways to lose weight that aren't tested or validated. It is based on a few simple equations that have been used for many years to calculate caloric information and have been validated through much use and testing. I believe that if young people were given this type of information through their school they could be informed early in life on how to keep healthy and to help prevent obesity as early as possible. This would lessen the chances of these children suffering the consequences of obesity, helping them live longer, healthier lives.

Conclusions:

This model gives the user a precise answer to the question of what they have to do in order to go from being overweight or obese to a healthy weight. It provides them with the ability to see the effects that different levels of exercise and caloric deficits have on their body weight. This will be very helpful in order to help people live a longer and healthier life as they have the information they need to reach a healthy weight and helps them feel less lost and confused about the process.

I would recommend trying this model to anyone who is looking to lose weight and is confused about how to do it. There are so many different opinions out there on the best or fastest way to lose weight, when in reality it is all based on the simple equation of making sure your calories out is higher than your calories in. This tool can be used by anyone to visualize a weight loss routine without having to actually do it, therefore giving them the ability to create the right plan for their lifestyle. This is something that doctors could use to help their patients come up with a routine that will help them reach their goal as well as fit their lifestyle. Overall, this model aims to create a way to fight the obesity rate in the United States and I believe if it is used correctly it can do just that.

VIII. APPENDICES

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