Cost-Benefit Analysis to Address Runaway Health Care Expenditures Through Lifestyle Modification Programs

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Abstract **– The cost of health care in the United States has been increasing at an annual rate of 9.8%, faster than the cost of living, since 1970. This is due to many factors, the most significant being preventable and manageable chronic conditions and diseases, known as comorbidities. These conditions and diseases are associated with individuals who classify as being overweight or obese, representing 68% of the United States population. This creates a strain on the health care system and the economy.**

Decreasing the number of overweight or obese individuals is necessary to reduce the prevalence of weight-related comorbidities. This can be accomplished through establishing and maintaining the proper energy balance between caloric intake and physical activity. The government leads many efforts to educate individuals on the importance of incorporating nutrition and physical activity into their daily lives to promote healthy behaviors. Since limited budgets for encouraging participation exist, a need for a system designed to assists policy makers in determining which age cohorts, or groups, given a level of adherence to recommendations, would result in the most benefit to stakeholders.

An analysis was conducted to determine which 10-year age cohort(s) should be targeted for health promotion in efforts to reduce the prevalence of overweight and obese individuals. Each alternative was evaluated based on its effectiveness versus the associated cost of promotion. Each age cohort's participation and predicted weight loss was simulated using a validated weight prediction model. Weight loss resulted from partial cohort adherence to nutritional and physical activity recommendations. Effectiveness was determined by weight loss, prevalence of comorbidities, and health care equity.

The analysis showed that if 90% of a given cohort adhered to government recommendations, the 60-year age cohorts' outcome would result in the greatest benefit for the smallest cost. For 30 and 60 percent adherence levels, analysis showed that the 60-year cohort would result in the largest benefit. The remaining alternatives were ranked based on their cost benefit. A sensitivity analysis was conducted to determine if the results were sensitive to changes of the importance of the benefit measures. The results demonstrated that the 60-year age cohort was the best alternative in all cases except when health care equity was most important.

Keywords **– risk management, decision support, tradeoff analysis, lifestyle behavior**

I. INTRODUCTION

The cost of health care is projected to rise from $8,050 per capita to over $13,650 in 2019, as shown in Figure 1 [1]. The most significant factor which has lead to this increase is the growing number of overweight and obese individuals, who make up approximately two-thirds of the U.S. population. These individuals suffer from an imbalance in energy expenditure, caused by high caloric intake and little to no physical activity. The Dietary Guidelines Advisory Committee (DGAC) has reported obesity to be "the greatest threat to public health this century" [2].

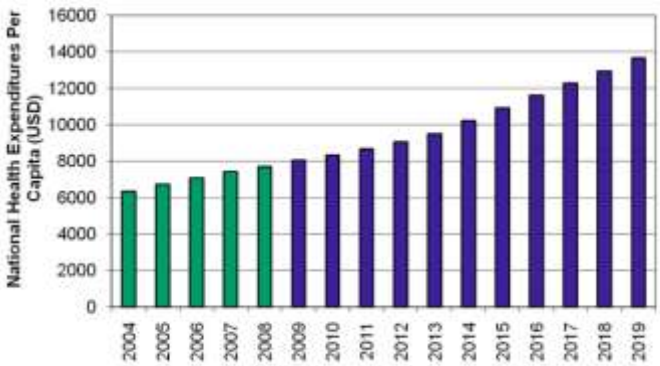

Fig 1. Projected increase in annual per capita health expenditures.

As an individual's weight increases, so does their risk of acquiring arthritis, hypertension, diabetes, and high cholesterol. The latter three are direct contributors to many other conditions and illnesses, including cardiovascular disease and stroke, the most costly of the comorbidities, shown in Table I [3][4]. With weight gains between 11-17 pounds, individuals experience an increase in the risk of acquiring coronary heart disease by 25%, which is the number one leading cause of death in the U.S. [3][5].

Table I
Estimated Annual Direct Medical Expenditures*

Cardiovascular disease and stroke**	$313.8 billion in 2009
Diabetes	$116 billion in 2007
Arthritis	$80.8 billion in 2003
* Different methodologies were used in calculating costs.	
** Includes heart diseases, coronary heart disease, stroke, hypertensive disease, and heart failure combined.	

It is important to decrease the number of overweight and obese individuals in order to decrease the annual medical expenditures associated with many chronic conditions and diseases. The overwhelming percentage of overweight and obese individuals not only creates a strain on the health care system but the economy as well. In 2003 it was estimated that the government lost over a trillion dollars in productivity due to absenteeism resulting from illness [6].

The Centers for Disease Control and Prevention (CDC) reported that comorbidities attribute to 75% of health care expenditures. Many studies have been conducted and

Manuscript received April 4, 2011. This work was supported in part by
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Systems Engineering and Operations Research Department
4400 University Drive, Fairfax, Virginia, USA
Sponsor: Dr. Lance Sherry, Director, Center for Air Transportation Systems Research, GMU
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scientifically prove that many of these comorbidities are preventable by modifying health risk behaviors. The four behaviors include excessive alcohol consumption, lack of physical activity, poor diet, and tobacco use [3]. The DGAC states "the leading causes of death for the past two decades have been tobacco use and poor diet and physical inactivity [7].

Specifically physical inactivity and poor diet have contributed to the growing number of overweight and obese individuals. Maintained weight decreases of 5-7% can prevent or delay diabetes; clinical trials have concluded a reduction of chance by 58%. Reductions in blood pressure and cholesterol can reduce an individual's risk of acquiring cardiovascular disease by 25% and coronary heart disease by 30% [3].

II. Problem Definition

The federal government has recognized obesity as a priority in preventing comorbidities [7]. The U.S. Department of Agriculture (USDA) and Health and Human Services (HHS) lead efforts to promote a nutritional diet and adequate physical activity based on evidence from clinical trails. They promote health through weight loss, accomplished when an individual's caloric intake is balanced with energy expenditure from physical activity. Clinical studies have shown that weight loss, adherence to recommendations, and maintained weight loss are consistent and outcomes are more beneficial when individuals participate in both incorporating a nutritional diet and physical activity [8].

Policy makers will benefit from risk management allowing them to identify and prioritize cohorts for health promotion efforts. A decision support system is needed to evaluate the effectiveness of government recommendations by ranking specific cohorts' outcomes when adhering to DGAC recommendations. This will allow the government to prioritize and target health promotion in order to receive the greatest benefit compared to the cost to promote healthy behaviors.

A. *Stakeholder Analysis*

The U.S. population and federal government policy makers represent the primary stakeholders in the system. They mutually benefit through increased economic productivity, lower health care expenditures, and health benefits from the adoption of healthy behaviors.

The secondary stakeholders include private industry policy makers. These stakeholders are comprised of health care providers, employee health insurance providers, and individual health insurance providers. They benefit by assuming a smaller risk associated with chronic disease treatment and the impact of chronic disease on productivity.

B. *Scope*

This system will be implemented in the U.S. to measure the effectiveness of recommendations on age cohorts to assess the associated cost benefit. The means of achieving adherence to nutritional and physical activity recommendations are not specified; however, the specified levels of adherence are assumed to be attainable.

The chronic conditions and diseases examined during this analysis include hypertension, diabetes, high cholesterol, and osteoarthritis because these are the most prevalent comorbidities and are risk factors for other chronic conditions and diseases. These conditions or diseases also have an increased likelihood of occurrence for individuals classified as overweight or obese.

C. *Assumptions*

(1) The metabolism of two individuals is identical if they have the same age, sex, height, and weight. This extends to identical speeds and amounts of weight change.

(2) There is no difference between two food items of identical caloric content, regardless of the amount of vitamins, fat, protein, carbohydrates, or other nutritional factors.

D. *Problem Approach*

Obtaining and maintaining a balance of energy is required to lower the number of overweight and obese individuals. These individuals are classified by their weight status, which is determined by Body Mass Index (BMI), which is an estimated measure of an individual's body fat. BMI is calculated using (1); weight measured in kilograms is divided by height measured in meters squared.

(1)

This method of body fat estimation was selected due to its efficiency, low cost, and overall validity, illustrated by its usage as a convention in body fat estimation. The Centers for Disease Control and Prevention (CDC) and other government agencies use BMI to classify individuals, assess their health risks and to collect and report data on weight status [9]. BMI indexes are classified by weight status displayed in Table II.

Table II
BMI Index Chart

BMI	**Weight Status**
Below 18.5	Underweight
18.5-24.9	Normal Weight
25.0-29.9	Overweight
30.0 and above	Obese

BMI will be used to measure weight change and classify weight status. The correlation between an individuals weight status and comorbidity will be used to predict the prevalence of a given condition or disease.

III. Design Alternatives

The alternatives being considered are ten-year age bracket cohorts, divisions of the U.S. population, from age 20 to 79. The ten-year age brackets were created to allow segmentation of the society into groups where many commonalities exist due to similarities in behavior, exposure, and experiences. The individuals in each cohort have shared experiences in the same time interval; distinguishing them from one another (e.g. baby boomers, Generation X, and Generation Y).

These brackets were analyzed to determine which cohorts' outcomes from participation in government recommendations would have the best cost benefit to policy makers. Each alternative will be evaluated based on 30, 60, and 90 percent adherence to the recommendations.

A. *Value Hierarchy*

The value hierarchy represents the decomposition of the evaluation measures used to assess the effectiveness of each design alternative. Effectiveness measures include the reduction in the number of overweight and obese individuals, gain in health care system equity, and a reduction in the probability of obtaining hypertension, diabetes, high cholesterol, or osteoarthritis. These measures will be discussed in detail in Section V. The primary objectives are shown in Figure 2. The resulting utility was compared against the implementation and maintenance costs associated with government efforts to promote adherence to health promotion recommendations.

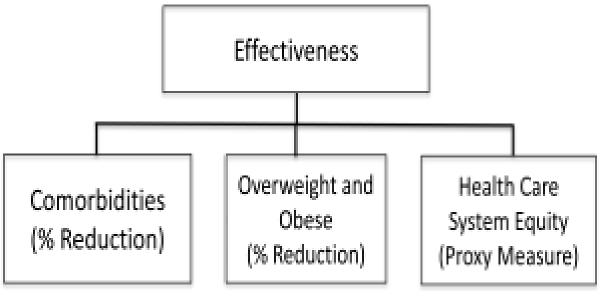

Fig. 2 Value Hierarchy for primary objectives and evaluation measures.

IV. MODEL AND SIMULATION

A representative population of each cohort was created, based on age, sex, height relative to age, and BMI relative to age distributions from the CDC. The weight loss of individuals in each cohort was continuously simulated based on the given adherence level to recommendations and using (2), a mathematical weight prediction model described in [10].

(2)

The model was developed by Thomas, et. al; it was validated by comparing the output, weight change, to historical data gathered by from The National Health and Nutrition Examination Survey (NHANES) using accurate measurements of body fat and energy expenditure based on the change of energy lost or stored [10]. Table III displays the explanation of the variables used in (2), the weight prediction model. The human body consists of fat mass and fat free mass, non fat components or lean body mass. Fat fee mass is calculated using (3).

Table III
Weight Prediction Variables

Cl	Energy Density of Fat Free Mass
dFFM/dt	Change in Fat Free Mass Over Time
dFM/dt	Change in Fat Mass Over Time
I	Caloric Intake per Day
E	Energy Expenditure

(3)

Intake represents the total number of calories consumed per day and is recommended in conjunction with a moderate physical activity level. Energy expenditure expands to (4), and accounts for all sources of daily energy expenditure.

$$E = RMR + DIT + SPA + PA \quad (4)$$

RMR is resting metabolic rate, the minimum amount of energy required to sustain organ function, found using (5).

$$RMR = a_i W^p - y_i (A_o - t/365) \quad (5)$$

The terms a_i, P_i, and y_i are constants that depend on the sex of the individual, W is the individual's weight, A_o is the individual's current age, and t is the number of days that have passed. DIT is dietary induced thermogensis, the amount of energy used to consume, process, and digest food, found using (6), where I represents energy intake, described earlier.

$$DIT = 0.075 \times I \quad (6)$$

SPA is spontaneous physical activity; the energy used when an individual adjusts his or her weight, or otherwise "fidgets," which averages to 348 kcal / day [11].

PA is energy expended via physical activity, found using (7).

$$PA = 2.844 \times W + 6.380 \quad (7)$$

A. *Inputs*

The inputs to the weight prediction model:

1. Age, sex, initial weight and height based on statistical distributions from the CDC.
2. Recommended moderate physical activity of 150 minutes per week, defined as an activity that increases an individuals heart rate and breathing (e.g. dancing, brisk walking, swimming, or bicycling) [12].
3. Recommended intake is specified in the Dietary Guidelines for America 2010 developed by the United States Department of Agriculture. Table IV shows the recommended values based on the individual's age and sex. These values represent baseline values for individuals who wish to maintain their current weight while exercising at a moderate level.

TABLE IV
Recommended Caloric Intake
for Moderate Physical Activity

Age	Males	Females
19–20	2,800	2,200
21–25	2,800	2,200
26–30	2,600	2,000
31–35	2,600	2,000
36–40	2,600	2,000
41–45	2,600	2,000
46–50	2,400	2,000
51–55	2,400	1,800
56–60	2,400	1,800
61–65	2,400	1,800
66–79	2,200	1,800

B. *Continuous Discrete Simulation*

The continuous simulation, models the impact of changes in both intake and physical activity taking into account changes in weight and mortality. For each alternative, a 1,000 representative individuals were discretely created; each individual's sex, height, and starting weight was calculated from BMI and were set based on known statistical distributions of the US population from the CDC.

The first portion of the simulation determines the daily change in an individual's weight, which results from adhering or not adhering to dietary and physical activity guidelines. Each individual intakes calories and expends energy through exercises; weight is predicted based upon the net energy value for that given day.

Each individual who does not adhere to the diet and exercise guidelines is randomly assigned a net energy value between -100 and 100 kcal, kilocalories [5]. This represents the typical dietary and physical activity fluctuations of individuals not participating in recommendations to control weight. Individuals, who adhere and reach a normal weight, are also assigned a net energy value between -100 and 100 kcal.

Individuals who do adhere to the program are assigned a caloric intake value according to their weight status. Those who are underweight (BMI < 18.5) consume 500 calories above the recommended value and those who are overweight or obese (BMI > 25) consume 500 calories below the recommended value [5]. The energy expended during physical activity is calculated by (7), the remaining components of energy expenditure (RMR, DIT, SPA) are calculated as described in section IV, and these values are summed and subtracted from the set caloric intake value to determine the net energy value using (4). The new fat mass and fat free mass values are then calculated and summed to determine each individual's new weight using (2).

The entire process is repeated for 365 days. As time progresses, an individual's BMI class change is determined by his or her height and weight at the end of each year. The mortality rate is then applied, according to both the individual's age and BMI class. If an individual is predicted to pass away that year, he or she does not continue through the simulation.

The model simulation is run for five years, at 5 years predicted weight change reached equilibrium. The simulation was in its entirety repeated 25 times for each design alternative in order to calculate the average weight loss over the 5 years used to conduct the benefit analysis.

C. Outputs

The outputs of the weight prediction model:

1. Weight change, represented as BMI.
2. Total number of individuals in each weight class.

V. Method of Analysis

The outcome of a given cohort's adherence to recommendations is determined by the analysis of its effectiveness, discussed in Section III and illustrated in Figure 2. Effectiveness is ultimately determined by weight loss.

A. Effectiveness is decomposed into the following measures:

1) Reduction of Comorbidities

As a result of adherence to physical activity and nutritional recommendations, the population will see an overall decrease in the incidence of comorbidities. The reduction in comorbidity was calculated using (9), where the probability of acquiring a comorbidity given a weight class was multiplied by the probability of an individual being in a certain weight class.

$$\text{Comorbidity rate} = \sum_i p(CR \mid i) * p(i) \tag{9}$$

Table V shows the probability of acquiring each chronic condition or disease, given a particular weight class, where weight class 1 is underweight, 2 is normal weight, 3 is overweight, and 4 is obese. The number of individuals in each BMI class is an output of the continuous simulation, discussed in detail in Section IV.

TABLE V

Likelihood of Obtaining Chronic Condition or Disease Given BMI Class[13]

Disease	**Probability**			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Diabetes	0.047	0.022	0.060	.086
High Cholesterol	0.102	0.268	0.409	0.398
Hypertension	0.216	0.234	0.366	0.484
Osteoarthritis	0.043	0.040	0.066	0.074

The reduction in comorbidity was determined by finding the difference in the comorbidity rate after individuals adhered to the recommendations throughout the 5 year simulation.

2) *Reduction in Obese and Overweight Population*

The percentage decrease of overweight and obese individuals is a measure of weight loss given adherence to recommendations to balance intake and energy expenditure. It is determined by the change in the percentage of the population with a BMI classification of overweight or obese at the end of a specified time period. This value is the primary output of the continuous simulation, discussed in detail in Sections IV.

3) Health Care System Equity

Equity is measured by a proxy scale which represents the long-term effect of program participation on health care costs or strain. It is found by (10), where L is a longevity factor and TC is the total expected cost savings.

$$Equity = L * TC \tag{10}$$

The total expected cost savings are determined, by the average annual health care expenditures based on the number of individuals in a given weight class. Table VI displays the average annual expenditures for each weight class [13]. The cost savings are found by subtracting the total expected cost at the beginning of the simulation from the total expected cost at the end. The number of individuals in each weight class is secondary outputs of the continuous simulation, discussed in detail in Section IV.

The longevity factor is used to scale the cost savings over the remaining years before an individual reaches his or her life expectancy. Table III shows the longevity factor used for each cohort.

TABLE VI

Average Annual Health Care Expenditure

BMI Class	**Average Annual Expenditure (Ci)**
Underweight	$3370.99
Normal Weight	$2714.00
Overweight	$3371.00
Obese	$4103.80

TABLE VII

Longevity Factors

Cohort	**Longevity Factor**
70	1
60	2
50	3
40	4
30	5
20	6

B. Cost

The costs of government health promotion efforts include both an implementation and maintenance cost. HHS has received a budget of $750 million toward prevention efforts to minimize the prevalence of comorbidities and promote healthy lifestyle behaviors [14].

Specifically, $298 million has been allotted for implementation of health promotion programs that locally focus on the four modifiable lifestyle behaviors referred to in Section I. The maintenance cost to continually collect health related statistics and inform individuals of new recommendations validated through clinical trials is $133 million [14].

To implement the proposed system it would cost $1.17 per person based on the current U.S. population. This value was used to determine the cost of adherence per person of a given cohort displayed in Table VIII. Maintenance costs would remain constant for each alternative.

TABLE VIII
COST PER PERSON WITH RESPECT TO ADHERENCE AND DESIGN ALTERNATIVES

Age-Cohort:	20	30	40	50	60	70
30 % Adherence	15.23	14.25	15.45	14.36	9.73	5.76
60 % Adherence	30.46	28.50	30.89	28.72	19.45	11.51
90 % Adherence	45.70	42.75	46.34	43.07	29.18	17.27

C. Utility Function

The utility for each alternative was calculated using the weighted value function in (11). Figure 3 represents the weights for each measure of the value hierarchy. The weight were determined using the smarter method; equity of the health

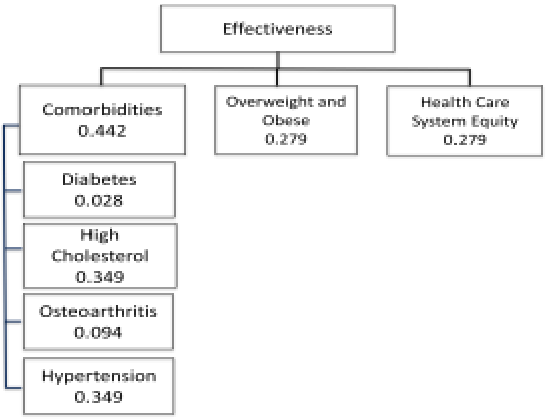

Fig.3 Decomposed value hierarchy with weights.

care system and the reduction of the overweight and obese population were ranked equally. The weights for reduction of comorbidities were ranked based on their associated costs illustrated in table I. Hypertension and high cholesterol were ranked equally because they are both contributors to heat disease, while diabetes was ranked next and then osteoarthritis.

The results from each design alternative were scored by normalizing the results produced by each cohort. Utility was calculated using (11), where W_i is the weight of the parameter and S_i is the score of that parameter.

$$Utility = \sum_i w_i * S_i \tag{11}$$

VI. Analysis of Results and Recommendations

Analysis shows that the 60-69 year age cohort offers the best benefit for 30, 60, and 90 percent adherence levels. A ranking of the alternatives is displayed in Table VII. The results are valid even though these individuals experience a decrease in metabolism as they age. HHS reports that the benefits associated with physical activity and diet are evident regardless of age [15].

The Agency for Healthcare Research and Quality (AHRQ), a department of HHS states that older individuals actually receive more overall benefit more from adhering to lifestyle behavior recommendations as opposed to younger individuals because they have a higher risk for comorbidity and the recommendations also help manage existing conditions such as blood pressure, cholesterol, diabetes, and osteoarthritis. The results are consistent with the AHRQ implications that society may gain a larger benefit from improving the lifestyle behaviors in older individuals, as compared against other age groups [15].

TABLE VII
Design Alternative Ranking and Utility by Adherence Level

	Effectiveness
Weight	1.000
60 Year Olds-90% Adhere	**0.878**
50 Year Olds-90% Adhere	0.859
40 Year Olds-90% Adhere	0.693
70 Year Olds-90% Adhere	0.634
60 Year Olds-60% Adhere	**0.537**
20 Year Olds-90% Adhere	0.519
50 Year Olds-60% Adhere	0.495
30 Year Olds-90% Adhere	0.471
40 Year Olds-60% Adhere	0.390
70 Year Olds-60% Adhere	0.355
20 Year Olds-60% Adhere	0.280
30 Year Olds-60% Adhere	0.257
60 Year Olds-30% Adhere	**0.214**
50 Year Olds-30% Adhere	0.142
70 Year Olds-30% Adhere	0.092
40 Year Olds-30% Adhere	0.084
20 Year Olds-30% Adhere	0.051
30 Year Olds-30% Adhere	0.035

A tradeoff analysis between cost and benefit was conducted to determine which design alternatives provided the greatest benefit to government policy makers for the smallest cost; this is represented in Figures 4, 5, and 6.

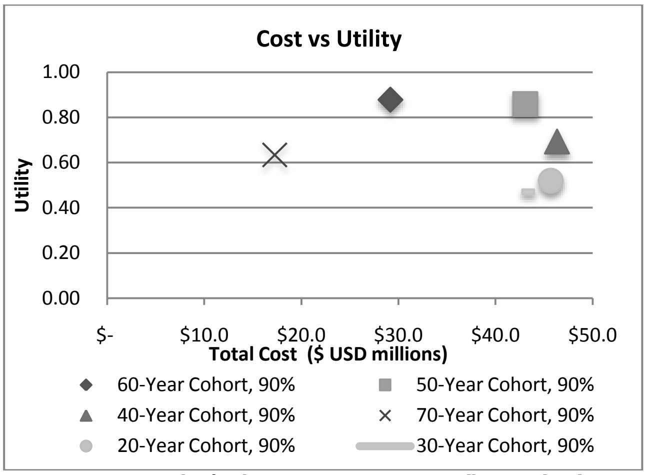

Fig 4. Graph of utility versus cost at a 90% adherence level.

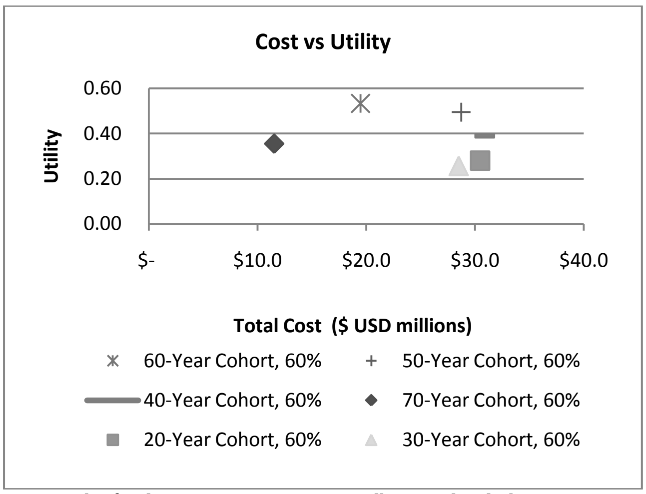

Fig 5. Graph of utility versus cost at a 60% adherence level, the maximum utility possible is 0.60.

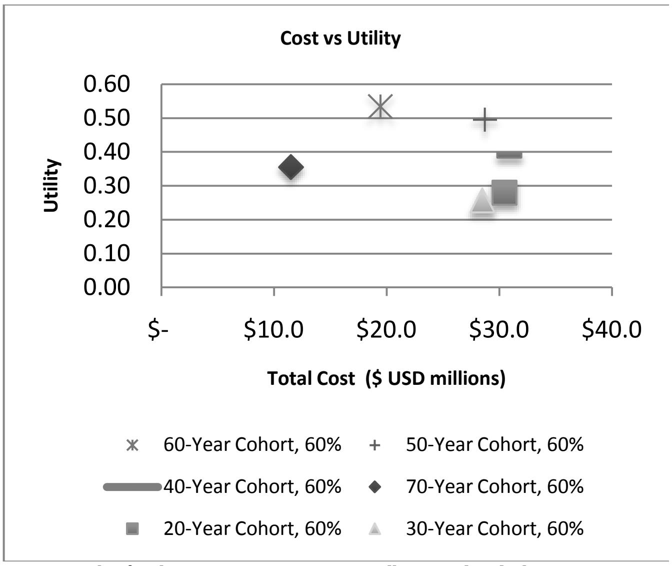

Fig. 5 Graph of utility versus cost at a 30% adherence level, the maximum utility possible is 0.30.

VII. Sensitivity Analysis

Sensitivity analysis was conducted to determine how the results were affected when more importance was placed on one measure of effectiveness over another. The results showed that changes in the importance of the measures did not affect the results; the 60-69 year age cohort remained the best alternative for government health promotion

VIII. Extensions and Further Research

Future research should be considered on how adherence levels can be achieved and the associated benefits and costs. This analysis assumed that the included adherence values were not only possible but would require a budgetary input equivalent to (10). Another area for suggested future research is the modification of the weight prediction model to take into account the nutritional content received from caloric content.

IX. Acknowledgements

This project would not have been successful without the support of our project sponsor, Dr. Glen Ackerman and our faculty advisors, Dr. Lance Sherry and Dr. Peggy Brouse. We would also like to thank the faculty of George Mason University's Systems Engineering and Operations Research Department. We would also like to give a special thanks to Mike Dupuy of George Mason University for aiding us with the completion of this paper.

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