DECEMBER 2021 M.Sc. in Industrial Engineering ESRA CEYLAN

REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

DIET PLANNING FOR DIABETIC PATIENTS USING MIXED INTEGER LINEAR PROGRAMMING

M.Sc. THESIS

IN

INDUSTRIAL ENGINEERING

BY

ESRA CEYLAN

DECEMBER 2021

DIET PLANNING FOR DIABETIC PATIENTS USING MIXED INTEGER LINEAR PROGRAMMING

M.Sc. Thesis

in

Industrial Engineering

Gaziantep University

Supervisor

Prof. Dr. Serap ULUSAM SEÇKİNER

by

Esra CEYLAN

December 2021

DIET PLANNING FOR DIABETIC PATIENTS USING MIXED INTEGER LINEAR PROGRAMMING

submitted by **Esra CEYLAN** in partial fulfillment of the requirements for the degree of Master of Science in **Industrial Engineering, Gaziantep University** is approved by,

Prof. Dr. Mehmet İshak YÜCE
Director of the Graduate School of Natural and Applied Sciences ……….............

Prof. Dr. Serap ULUSAM SEÇKINER
Head of the Department of Industrial Engineering ……….............

Prof. Dr. Serap ULUSAM SEÇKINER
Supervisor, Industrial Engineering
Gaziantep University ……….............

Graduation Date: 16 December 2021

Examining Committee Members:

Prof. Dr. Serap ULUSAM SEÇKINER
Supervisor, Industrial Engineering
Gaziantep University ……….............

Doç. Dr. Süleyman METE
Industrial Engineering
Gaziantep University ……….............

Dr. Öğr. Üyesi Yunus EROĞLU
Industrial Engineering
İskenderun Technical University ……….............

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Esra CEYLAN

ABSTRACT

DIET PLANNING FOR DIABETIC PATIENTS USING MIXED INTEGER LINEAR PROGRAMMING

CEYLAN, Esra
M.Sc. in Industrial Engineering
Supervisor: Prof. Dr. Serap ULUSAM SEÇKİNER
December 2021
61 pages

Diabetic diet is an important treatment procedure for diabetic patients. Necessary nutritions should be consumed in proper sizes for a long-life health. In this study a mathematical model has been constructed for diabetic menu planning. Literature about menu planning showed that there is infancy in diabetic menu planning, current studies do not deal with carbohydrate consumption, which is an essential factor for diabetic patients. According to the findings from nutrition treatment recommendations, a mathematical model has been constructed with an objective function that minimizes the total carbohydrate consumption. In this study, it was planned to create a menu with integer programming model and a wide variety of menus were presented to diabetic patients. The model was written separately as 2, 3 and 5-day menus in the GAMS optimization program, and at the last stage, 28-day menus were obtained by solving each of them. This study can be assumed as a preliminary work of the diabetic menu planning with the aim of solving the problem via completing the necessary nutritions parameters.

Key Words: Diabetes, Integer Programming, Menu Planning.

ÖZET

KARIŞIK TAMSAYILI DOĞRUSAL PROGRAMLAMA KULLANARAK DİYABETİK HASTALAR İÇİN DİYET PLANLAMASI

CEYLAN, Esra
Yüksek Lisans Tezi, Endüstri Mühendisliği
Danışman: Prof. Dr. Serap ULUSAM SEÇKİNER
Aralık 2021
61 sayfa

Diyabetik diyet, şeker hastaları için önemli bir tedavi prosedürüdür. Uzun ömürlü bir sağlık için gerekli besinler uygun ölçülerde tüketilmelidir. Bu çalışmada diyabetik menü planlaması için matematiksel bir model oluşturulmuştur. Menü planlama ile ilgili literatür, diyabetik menü planlamasında bir bebeklik dönemi olduğunu, mevcut çalışmaların diyabetik hastalar için önemli bir faktör olan karbonhidrat tüketimini ele almadığını göstermiştir. Beslenme tedavisi önerilerinden elde edilen bulgulara göre, toplam karbonhidrat tüketimini en aza indiren objektif bir fonksiyona sahip matematiksel bir model oluşturulmuştur. Model, GAMS optimizasyon programında 2, 3 ve 5 günlük menüler olarak ayrı ayrı yazılmış ve son aşamada her biri çözülerek 28 günlük menüler elde edilmiştir. Bu çalışma, gerekli beslenme parametrelerini tamamlayarak sorunu çözmek amacıyla diyabetik menü planlamasının bir ön çalışması olarak kabul edilebilir.

Anahtar Kelimeler: Diyabet, Tamsayı Programlama, Menü Planlama.

"Dedicated to my family"

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Dr. Serap ULUSAM SEÇKİNER for her guidance and support throughout the study. I am thankful for her encouragement and motivation.

I would like to thank, RDN. İrem NECİ ÜNAL for his support throughout my thesis. I am thankful for his encouragement and motivation.

I would like to specially express my love and gratitude to my parents, Tülin CEYLAN and Ayhan CEYLAN for being by my side and supporting me in everything, always best wishes, and I will always be with them.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS

i	Food Indices
j	Meal
k	Day of the Month
l	Side Foods
x_{ijk}	Food Consume Variable
y_{ljk}	Beverage Consume Variable
e	Daily Energy Requirement
c	Daily Carbohydrate Requirement
f	Daily Fiber Requirement
fr	Daily Sugar Requirement
cl	Daily Cholesterol Requirement
sy	Daily Saturated Fat Requirement
s	Daily Salt Requirement
A	Daily A Vitamin Requirement
V	Daily C Vitamin Requirement
cp_l	Carbohydrate Values of the Main Meals
c_i	Carbohydrate Value of the *i.* food
f_i	Fiber Value of the *i.* food
fr_i	Fructose Value of the *i.* food
y_i	Fat Value of the *i.* food
sy_i	Saturated Fat Value of the *i.* food
s_i	Salt Value of the *i.* food
k_i	Calcium Value of the *i.* food

LIST OF ABBREVIATIONS

ADA	American Dietetic Association.
BMI	Body mass index
CH	Carbohydrates
DKA	Diabetic Ketoacidosis
DM	Diabetes Mellitus
FNDDS	Food and Nutrient Database for Dietary Studies
GFR	Glomerular Filtration Rate
IDF	International Diabetes Federation
IGT	Impaired Glucose Tolerance
LDL	Low-Density Lipoprotein
HDL	High-Density Lipoprotein
LP	Linear Programming
MILP	Mixed Integer Linear Programming
MNP	Medical Nutrition Therapy
NP	Non Deterministic Polynomial Time
PHP	Hypertext Preprocessor
PV	Prerrow Composite Value
SNS	Social Networking Services
TSI	Turkey Statistical Institute
WHO	World Health Organization

CHAPTER I

INTRODUCTION

1.1 Motivation of Study

The process of choosing the most suitable one out of multiple possible options based on the current possibilities and conditions to achieve one or more future goals is called the decision-making process. For a decision problem to exist, there must be more than one choice of behavior and the results for each behavior must have different returns. These different returns are determined by the defined purpose or objectives. The model created by expressing the goals or objectives and constraints of a decision problem mathematically is called the decision model. The mathematical expression of an objective is called an objective function. The decision model consists of the objective function, constraint, and decision variables. The expression solution of the decision model refers to the presence of values of decision variables that provide constraints and give the best objective function value. Each of the possible values that decision variables can get represents an option. In other words, determining the decision variable values by solving the decision model means choosing the option that gives the best goal function value from among the possible options.

Diabetes is a disorder in the body's mechanism of converting sugar into energy. It is important in the treatment of diabetes in nutrition planning. Like every individual who wants to live a healthy life, diabetic patients also need to have adequate and balanced nutrition. Blood sugar rises in diabetic patients who do not have adequate and balanced nutrition. This situation causes significant damage to various organs. Therefore, it cannot be ignored how important it is for diabetic patients to have an adequate and balanced diet under the determined nutritional plan.

1.2 Aim of the Thesis

The diet plan for diabetes patients is created by taking into account the amount of energy and nutrients that the patient should take daily. It is desirable to create a nutrition plan that will provide these values as much as possible. The problem investigated in this study is to obtain the necessary nutritional values while minimizing the daily total carbohydrate consumption for diabetic patients, considering a maximum limit that the person wants to spend for one month's food consumption as a budget. For this purpose, it has been tried to bring a solution to this problem by proposing a very diverse food list.

1.3 Importance of the Thesis

As in the world of mathematical modelling techniques and menu planning, literature in Turkey, numerous studies have shown that there are only two studies on diabetic menu planning. The first of these studies, McCann-Rugg et al. (1983). [1] They set up a target program to maximize the nutritional value of foods. The other study is the model proposed by Kazan (2011). [2] The purpose of these studies is to minimize the cost. None of these studies have been shown to consider carbohydrates as an objective function, but not the importance of carbohydrates for diabetic patients. Since carbohydrates affect the glucose level in the blood, this study aims to get the necessary nutritional values and minimize total carbohydrate consumption.

1.4 Structure of the Thesis

The Sections of this study are as follows; The definition of the problem will be presented in Section 2. In Section 3 proposed mathematical model will be described. In Section 4 results of the solved model will be discussed.

CHAPTER II

LITERATURE REVIEW

2.1 Diet Planning

The first word that comes to mind when it comes to Operations Research is optimization. Optimization can be defined as "achieving the best". This means finding the optimal (best, most efficient) solution to the problems by using the available resources for the purpose. Operations, the application of scientific and especially mathematical methods in solving and examining complex problems; Operations research, on the other hand, is the research and examination of any problem according to the operational method. [3]

Among the most important scientific developments seen in the middle of the twentieth century, the developments in linear programming took the top place. The impact of linear programming on the business life of companies has been phenomenal since the 1950s, with most companies starting to use computers. [4]

Linear programming is a mathematical modelling method designed to optimize the use of limited resources. There are successful linear programming applications in fields such as health systems, military, agriculture, industry, transportation, economics, and even behavioral and social sciences. The use of the method has increased with the developments in computer software. [5]

In real life, multi-objective mixed integer programming problems are very common. However, since the Pareto limits of such problems are not well understood, models developed for integer programming problems have been tried to be applied to these problems. In the literature, there are methods developed for multi-objective mixed-integer problems and their applications to real life. In the research of Wetherilt and Dağlı on "Menu Planning with Computer" within the scope of TUBİTAK, they developed 2 types of models: menu development with interactive programming technique and food item analysis with linear programming technique. In the method of developing menus with interactive programming technique, compatible and low-cost menus were entered into the computer by hand, whether they complied with the economic situation of a family of 4, whether they met energy and food requirements and corrections were made.

In the nutrient analysis method with the linear programming technique, the lowest cost food lists were determined that provide adequate and balanced nutrition of the people. As a result, low-cost menu and food options that meet the requirements were created in both methods [6].

In Turkey, the first mathematical model in menu planning was made by the Armed Forces in 1967. In this study, a planning was made on nutrients according to the values of energy and nutrients required by the soldiers under certain conditions with the linear programming method. In the planning, winter and summer prices of foodstuffs were calculated and separate models were established for both seasons, and the menu was made to have minimum cost. With this study, various menus such as cold climate menu, food menu, strong menu, submarine menu, prison menu, school menu, hospital menu were created and it was seen that the model could solve the problem of feeding the armed forces. [7]

In his research in Reyhan in 1990, he presented an approach to balanced and adequate nutrition with goal programming method. In this study, foods that will meet the energy and nutrient needs of moderately active men in the 20-49 age group, with minimum cost, will be included in the 7-day lunch menu were created. The model solved using Lindo package program; it was concluded that it can provide a solution to adequate, balanced and economical nutrition. [8]

Oral (1999), who conducted research on multi-purpose models in menu planning, dealt with military students in the Turkish army in his 1999 study. In this study, in which most of the menu planning rules were taken into account, a multi-purpose programming model was established. This model has been formulated for 3 purposes: minimizing the total cost of the menu, maximizing students' preferences for the menu, and maximizing the energy content of the menu. In the model that was solved using the GAMS package program, menus were obtained in accordance with the objectives. [9]

Another study conducted on patients with diabetes is Koç's study in 2001 (Koç, 2001). Again, it was conducted in cooperation with dietitians. In this research, minimum cost breakfast, lunch and dinner menus were created within the needs of diabetic patients with target programming. The model was solved with Lindo package program and the program developed using Turbo Pascal programming language and the results were compared. Accordingly, it was emphasized that the interaction process of the developed program is faster and it can be the solution not only for diabetics, but also for all nutritional problems. [10]

Garille and Gass (2001) reviewed Stigler's diet problem, its impact on linear programming and operations research, and determined minimum cost diets using updated nutritional and cost data. [11]

Another approach to balanced nutrition has been proposed by Kazan (2001). Kazan, in his work using equal priority goal programming; It handled moderately active men between the ages of 20-39 and planned to create nutrients that will meet their energy and nutritional needs, with minimum cost and must be taken every one day. Finally, the model was solved in the Lindo package program and as a result of the solution, a menu consisting of daily nutrients was obtained in appropriately with the objectives.[12]

Valdez-Pena et al. (2003) focused on individual meal preparation for non-therapeutic adult diets. Step-by-step technique preparation for problem modelling as a Mixed Integer Linear problem is suggested and evaluated with four separate subjects by reading their expectations, constructing a model in Excel and resolving it with a commercial MILP solver. The preference function to optimize is the sum of the piece wise linear approximations of the quadratic frequency-preference function for each of the menu items available for assignment. [13]

Kashima et al. (2009) focuses on daily food close to our lives and suggests a well-balanced meal planning system as a preventive measure of lifestyle-related diseases. The interface is designed using a web-based frontend and offers multi-user services and menu knowledge sharing features such as social networking services (SNS). The framework is built on a web server running Apache (HTTP server software), MySQL (database management system) and PHP (scripting language for dynamic Web pages). For menu planning, a genetic algorithm is used to understand this issue as multidimensional 0-1 integer programming. [14]

Funabiki et al. (2011) proposed time-limited menu planning problems for two-phase cooking and demonstrated the NP-completeness of its decision-making problem by reducing the NP-complete knapsack problem. They then introduced their heuristic algorithm based on a simple, greedy approach to the problem of snacks, where food is sequentially selected from the menu in the descending order of food priorities. They applied the algorithm to produce a one-week menu plan from 53 food candidates, where the result verifies the efficacy of their approach. [15]

The goal of the Kljusurić et al. (2014) study was to question the applicability of linear programming (LP) and fuzzy logic optimization in individual menu planning for pregnant women with gestational diabetes. The LP model was used to optimize the overall total energy consumption and the limitations extracted from the ADA exchange list. However the results showed that LP optimization would not result in menus in accordance with the recommended number of units in the ADA Exchange List, and thus those menus could not be used as sample menus. In order to address the contradictions between the ADA list and the objective function, a fuzzy logic model for energy intake and individual ADA subgroups for macro and micronutrients has been implemented. The Prerrow Composite Value (PV) was optimized, including energy and all subgroups observed. The Fuzzy logic approach proved to be efficient for optimisation. In general, fuzzy logic optimization in nutrition can lead to individual tailoring of daily menus to account for personal differences. [16]

Baykasoglu et al. (2016) suggested that monthly menu planning in mass diets is a dynamic decision-making problem that includes many purposes, restrictions and factors, such as healthy eating, limited budget, seasonal impact, being able to produce food for many people in a limited period of time, people's satisfaction, interactions between scheduled meal times, the order of nutrients served together. In his research, he has built an integrated decision support system that takes into account multiple operational and practical constraints and objectives at the same time. The real-life implementation of the proposed decision support system is also carried out with real data for model solution in DEU Canteen-Cafeterias Department. [17]

Ali et al. (2016) argued that creating and preparing a nutritious and healthy menu manually is difficult, costly and time consuming. Their goal in their research is to improve a mathematical model for dietary planning that satisfy the necessary nutrition for middle school students and minimizes the budget. The data were obtained from various boarding schools and the Ministry of National Education. According to them, the aim of nutrition preparation, which is a well-known optimization problem, is to find the best possible optimal solution. It was then solved using an optimization approach with Model Zero One Integer Programming. They came to the idea that this model could be used to solve other problems related to diet planning, such as military, nursing home hospitals and universities.[17]

Yulina and Hajar (2017) have developed a program that can be used as a food menu for children and adolescents for early prevention of type 2 diabetes. The algorithms used by the software are the Definition of Restriction Satisfaction Problem and traceback algorithms and have been developed with the Java programming language and MySQL database. From the test results of the system created, it was observed that this application allows parents to know their health status and they can choose a healthy meal menu with the calories that children/adolescents need. [18]

Dhoruri et al. (2017) reported that a food menu with an acceptable amount of nutrients was organized taking into account the amount of calories, proteins, fats and carbohydrates. In this research, the Target Programming model was used to assess optimal dietary menu variations for patients with diabetes mellitus by paying attention to optimal costs. Based on hospital results, optimal menu variations have been evaluated using the Aim Programming model and completed using the LINGO computer software.[19]

Marrero et al. (2019) claim that promoting safe and stable patterns in the populace is one of the most important action steps for policymakers around the world when it comes to lifestyles related to heart attacks, overweight, diabetes, etc. The disease is even more prominent when a large percentage of patients spend only consuming fast or over processed food, and when there are children and adolescents whose lifestyles consist of sedentary life. The creation of safe and nutritious food lists has become a typical activity for doctors and nutritionists, and they have proposed a multipurpose formularization of the Menu Planning Problem for school cafeterias. [20]

In a research by Lee et al. (2020) to help patients with breast cancer select the right food in their day-to-day meal, it will be demonstrate how to use various mathematical programming methods to prepare a proper and balanced diet plan that meets all the nutrient constraints with the minimum cost of breast cancer patients. They claimed that in methodology, there are two mathematical programming methods to be used which are integer programming methods and binary integer programming methods. There are two sets of data containing 100 food items for the small data model and 426 food items for the big data model. After all of this study, breast cancer patients who may have sufficient nutritional value should be able to include at least a one-day menu and a weekly menu, they said. [21]

2.2 Diabetics

Diabetes, which is at the forefront of diseases of the age, is a type of disease that plays a leading role in the formation of many deadly diseases and is very common all over the world. Diabetes Mellitus, the full name of the disease, means sugary urine in Greek. Fasting blood glucose level in healthy individuals is in the range of 70-100 mg / dL. If the blood sugar level exceeds this range, it usually indicates diabetes. The chronic hyperglycemia of diabetes causes long-term damage to different organs, especially the eye, kidney, nerve endings, heart and vessels [22]. To prevent acute complications of the disease and prevent long-term damage or any negative reaction that may occur, the individual should receive self-treatment care training and continuous medical treatment [23].

The treatment of this life-long disease is to provide the individual with a change of lifestyle by first getting medical nutrition therapy and exercise habits, to get support from medical treatment when necessary, and to enable the diabetic individual to perform diabetes care on his own by teaching this discipline to the individual [24].

The world has been flooded with metabolic diseases triggered by the new lifestyle that emerged as a result of economic development. With these developments, the proportion of Type 2 Diabetes Mellitus has increased in all countries. This increase continues rapidly and shows a pandemic picture worldwide.

While the number of adults with diabetes between the ages of 20-79 in the world affected 285 million people with a frequency of 6.4% in 2010, it is estimated that this number will increase by 7.7% to 439 million in 2030. The number of adults with diabetes is expected to increase by 69% in developing countries and 20% in developed countries from 2010 to 2030 [25]. The prevalence of diabetes has risen faster in low- and middle-income countries than in high-income countries over the past decade [26]. Increased obesity and physical inactivity are the leading causes of this increase [27]. Diabetes caused 1.5 million deaths in 2012. In addition, high blood glucose levels due to diabetes increased the risk of cardiovascular and other diseases, and in addition, led to 2.2 million deaths. 43% of 3.7 million deaths in total occur before the age of 70, so it is reported that this percentage is higher in low and middle-income countries than in high-income countries [26].

Diabetes, whose prevalence has increased steadily over the past few decades, is seen as one of the biggest global epidemics of the 21st century [26, 28]. According to the International Diabetes Federation (IDF) 2015 Diabetes Atlas, diabetes caused 5 million deaths in the 20-79 age group in the world. While there are 415 million (8.8%) people living with diabetes in the same age group, it is expected that this number will reach 642 million (10.4%) in 2040; in other words, one out of every 11 adults will have diabetes in 2040. It is predicted that there are 318 million (6.7%) people with a high risk of developing the disease, and this number will increase to 481 million (7.8%) in 2040 [13]. In addition, it is estimated that gestational hyperglycemia affects 20.9 million (16.2%) live births in the 20-49 age group, and one in 7 births is damaged due to gestational diabetes [28].

According to the IDF 2015 Diabetes Atlas of the number of people with diabetes in the world, 215.2 million men and 199.5 million women, according to gender, were found to be 269.7 million in urban areas and 145.1 million in rural areas. The total population under the age of 15 is around 1.9 billion in the world and the incidence of type 1 diabetes is increasing in many countries, especially in children under the age of 15. Despite different geographical variables, it is estimated that type 1 diabetes increase is 3% each year. There are 542,000 people in the 0-14 age group with type 1 diabetes, and the top 3 most reported countries are the USA, India, and Brazil. It is reported that Finland, Sweden, and Kuwait, respectively, lead the way with the highest incidence rates, with type 1 diabetes development in 86,000 children under the age of 15 each year [28]. In the light of all these data, diabetes is an important public health problem with an increasing prevalence [26]. Turkey, according to the IDF Diabetes Atlas 2015, while prevalence when viewed with the highest number of people with diabetes and 12.8% among European countries 6.3 (5.7 to 7.5) in Germany with 6.5 million people 5.9-7.5 million and Russia's 12.1 (6.2-17.0) a million diabetics are ranked third [28]. Turkey Diabetes Epidemiology (TURDEP-1 (1997-98)) is 7.2% higher than the operating frequency of diabetes mellitus in Turkey [11] TURDEP-2 (2010) in the prevalence of diabetes mellitus has been reported as 13.7% [30]. Turkey Statistical Institute (TSI) 2012 health survey data on diabetes, and individuals age 15 and over according to their declaration (6.8%) and the Journal of Turkish World Research Center of Public Health. 2018; 3 (1), in terms of the disease groups diagnosed by the physician in 28 (6.7%), it ranks 5th [1]. In addition, in the National Burden of Disease study, diabetes ranks third both among the top 10 chronic diseases and among the top 10 diseases that cause death [31] [32].

Diabetes is a metabolic disease that progresses with glucose circulating in the blood, that is, high blood sugar. The insulin hormone secreted from the pancreas regulates glucose metabolism in the body. Incomplete or no secretion of this hormone causes diabetes. The biggest energy source of all cells in the human body is glucose, that is, blood sugar. The brain, on the other hand, only uses glucose as an energy source. Carbohydrates, fats, and proteins are taken with food are broken down into building blocks such as glucose, fatty acids, and amino acids in the intestines and pass into the circulatory system. For glucose to be used as an energy source, it must enter the cell from the circulatory system. This is where the hormone insulin comes into play. Insulin hormone secreted from the pancreas into the bloodstream plays a role in glucose entering the cell from the blood. In case of decreased insulin secretion from the pancreas, the entry of glucose into the cell will be impaired, and the glucose level in the blood increases and diabetes develops. It is quite wrong to consider diabetes only as high blood sugar and to simplify this disease. High blood sugar circulating in the blood; causes many diseases by accumulating in capillaries, organs, and nerves [33] [34].

2.2.1 Physiopathology

Insulin resistance: Glucose cannot be sucked into the cell (at the post-receptor level) and cannot be utilized as energy due to problems in the use of the insulin produced by the organism due to cell-receptor disorder (has intracestic hypoglycemia). Insulin is inadequate in tissues, especially muscle and adipose tissue, and glucose intake decreases in muscle and fat cells [35].

Decrease in insulin secretion: Excessive increase in glucose production in the liver is due to the pancreas's inability to secrete enough insulin in response to blood sugar levels. Therefore, insulin secretion disorder and insulin resistance disorder (cortisol, growth hormone, and adrenaline; dawn phenomenon) are responsible, which are more active in the morning. Generally, insulin resistance dominates the picture for many years, starting before type 2 diabetes, and a serious decrease in insulin secretion becomes prominent in the advanced stages of diabetes or during intervening diseases [35].

2.2.2 Epidemiology, Prevalence, and Incidence

Epidemiological studies showing the prevalence of diabetes are often based on age and self-declared diagnosis. In population studies, the differential diagnosis of diabetes, namely type 1 and type 2 DM patients, is difficult to differentiate. The information published by the International Diabetes Federation (IDF) includes the latest author's opinions. Although it does not reflect the total prevalence, 85-95% of all adults are type 2 diabetes [36].

Between 2007 and 2025, it is predicted that the total age-adjusted prevalence will increase from 6% to 7.3% for type 2 diabetes and from 7.5% to 8% for Impaired Glucose Tolerance (IGT) in 18 years. Compared to 2007 and 2025, the absolute increase is that diabetes in the 20-79 age range from 246 million to 380 million; It indicates that the IGT will increase from 308 million to 418 million. The prevalence is highest in the Eastern Mediterranean, and the Middle East is followed by North and South America. This observation reflects the increasing life expectancy and the general aging of the North American population. The Western Pacific region, especially China, will show the biggest increase (50%) in 2005 with 100 million people. The most common diabetes is in the 40-59 age group. However, by 2025, it will be equivalent to 60-79 years old and will reach 166 and 164 million worldwide (12). Comparative rates in the European region are 1.6% in Iceland and 7.9% in Germany and Austria. UK rate is 2.9% and the absolute rate is 4%, adjusted for age. It is assumed that in 2025 the adjusted rate will increase to 3.5% and the absolute rate to 4.6% (it will increase from 1.7 million people to 2.6 million [37].

The international and the rural and urban epidemiologic research conducted prospectively PURE (Prospective Urban and Rural Epidemiological Study) study is based on 2009-2012 data for Turkey, one of every five people between 38-73 years of age is advanced diabetes, a third of this rate over sixty years It has been reported that blood sugar control is insufficient in 80%of diabetics. All these research results can be subtracted from; Turkey's incidence of diabetes increased from 13% in 2009 to 17.9% in women in our country compared to men, and the probability of developing diabetes was shown to be over 3% [38].

The World Diabetes Foundation, a leading global funder of diabetes prevention, has published its work on how healthcare professionals will leverage emerging digital solutions to control, diagnose, and find diabetes solutions, ultimately enabling people with diabetes to lead a full, complication-free life. The foundation says that about 350 million people in low and middle-income countries live with diabetes, 77% of whom do not receive adequate care, and if diagnosed early, diabetes can be managed. Yet it has been observed that many healthcare professionals in low- and middle-income countries lack the skills and resources to prevent, diagnose and treat diabetes. The discovery of insulin in 1921 revolutionized the treatment of diabetes, and today it is believed that technology is driving change in healthcare [39].

2.2.3 Type 2 DM Features

- It usually occurs after the age of 30 and has a strong genetic predisposition. As the genetic density in the family increases, the risk of diabetes increases in future generations, and the disease begins to appear at an earlier age.
- Patients are often obese or overweight (BMI:> 25 kg / m^2).

- Patients may be seen on a long-term hyperplasia course or later periods when cell reserve decreases, while initially not prone to Diabetic Ketoacidosis (DKA).
- Many patients do not have the first symptoms. However, some patients may consult a doctor for reasons such as blurred vision, numbness and tingling in the hands and feet, foot pain, recurrent fungal infections, or wound healing [35].

2.2.4 Type 2 Diabetes Treatment

Medical Treatment: The primary goal in diabetes treatment is to prevent the development of Type 2 DM in high-risk individuals, and the most important point in the treatment of Type 2 DM is the individualization of the treatment. The approach to the treatment of patients with type 2 diabetes has greatly changed in recent years. International authorities on this issue publish up-to-date treatment algorithms one after another. Most of these algorithms are supported by evidence-based studies but are predominantly based on expert opinions. While previous algorithms emphasized the lowering of glycemic control targets, current algorithms recommend individualization of glycemic control targets under the characteristics of the patient and starting insulin and combination therapies earlier than traditional step therapy [35].

Medical Nutrition Therapy (MNP) in Diabetes:

Medical Nutrition Therapy consists of four basic application steps:

- Evaluation: Individual evaluation of parameters such as anthropometric measurements, social life history, food consumption history, laboratory examinations, blood pressure, physical activity history, medical treatment, willingness to change lifestyle for the recommendations to be given to the diabetic individual.

- Nutritional diagnosis and target determination: Determining the nutritional diagnosis as a result of evaluating the nutritional status of the individual and other parameters with the food consumption history, determining the appropriate energy and macronutrient requirement level for the individual.

The diabetic individual and the dietitian together determine the achievable goals and specific applicable behaviors.

- Nutrition intervention, education: As a result of the evaluation, the nutritional diagnosis is determined, the existing problems related to nutritional behavior are determined. Nutritional diagnosis is determined as carbohydrate intake that is not suitable for the needs, fat consumption is higher than the required levels, carbohydrate consumption varies from meal to meal, and excess consumption frequency of foods with the high glycemic index. The treatment goal varies from individual to individual. The goal for every person with diabetes may not be to achieve blood sugar control. For some individuals, the goal may be to maintain blood sugar control, while maintaining control of the blood lipid profile may be to control body weight for another. To provide simple and detailed training, one-on-one interviews are made with the person with diabetes.

- Follow-up: It is necessary to evaluate practices, compliance, and clinical results, to identify existing problems and focus on their solutions. Food consumption, fasting, and postprandial blood glucose monitoring results are evaluated together at this stage. If necessary, mealtime and meal content are rescheduled according to current changes in medical treatment [35].

For MNP to succeed, it is necessary to transfer the nutritional habits of the diabetic and the socioeconomic appropriate nutrition plan to the patient by supporting nutritional education, as well as monitoring the behavior change in understanding the information given and converting it into practice, and the solution of the problems should be provided with the patient. Here, the member of the diabetes team should play a guiding role, not a sanctioning one [35].

The effectiveness of MNP is evaluated within 6 weeks to 3 months after starting treatment. If a clinical improvement is detected in glycemic control at the end of the third month, the dietician should refer the patient to a physician for evaluation of medical treatment. The administration of MNP in an individual with diabetes who is diagnosed with diabetes and directed to a dietician, includes 3-4 visits, each lasting

45-90 minutes, completed within 3-6. It continues with at least one annual consultation to support lifestyle changes and evaluate treatment.

Macro Nutrients in Diabetes Treatment:

- Evidence suggests that there are no ideal ratios of energy from macronutrients for all people with diabetes.
- The distribution of macronutrients in individuals with diabetes is individualized based on the treatment goals, individual preferences, and current eating habits. 45-60% of total energy need can be met from carbohydrates, 10-20% from proteins, 20-35% from fat. <7% of the energy can be met from saturated fat, trans fat intake should be <1%.
- The proportions of energy to be provided from carbohydrates, protein, and fat may vary according to metabolic goals and the preferences of the diabetic individual. It is not correct to give recommendations according to a standard distribution. However, providing <30% of the energy from fat and <7% from saturated fat is effective in preventing cardiovascular diseases.
- Very low carbohydrate diets are not recommended because they limit the consumption of too many nutrients with vitamins, minerals, fiber, and energy sources [40].

Carbohydrates (CH):

- The effect of type and amount of carbohydrate is important in MNP of diabetes [41]. Recent studies show that a high-carbohydrate diet (> 60%) increases blood lipids, especially triglycerides and glycemic response.
- The dietary model required to be healthy should include foods with CH as whole grains, fruits, vegetables, and low-fat milk.
- In the treatment of diabetes, diets with low CH that keep the daily CH intake below 165 g are not recommended. The WHO recommends that dietary carbohydrates make up at least 55% of total energy intake in "normal" healthy individuals, so the minimum carbohydrate value for 1200 calories has been calculated as 165 grams.
- In individuals taking only MNP or using oral antidiabetic drugs or insulin with MNP, the intake of CH should be distributed between meals and snacks and should not change from day to day, but in similar amounts.

- Monitoring of CH uptake, utilizing CH counting, change lists, or experience-based computation, is the key to achieving glycemic control.
- People with type 1 and type 2 diabetes should adjust their insulin doses according to their carbohydrate intake (carbohydrate-insulin ratio) as they adjust their insulin or use an insulin pump during mealtimes. Therefore, detailed nutrition training should be given to calculate the number of CH (30-33) and CH/insulin rate and insulin sensitivity factor, and the effects of carbohydrates on blood sugar should be explained by establishing a relationship between individual blood sugar measurement results and consumption records and food.
- It should be emphasized to individuals who apply carbohydrate count as a meal planning method, that an increase in energy intake will cause an increase in weight, and that protein and fat consumption other than carbohydrates should not exceed the amounts given in the treatment.
- Considering the glycemic index and glycemic load of CHs in addition to the daily total amount of CH taken may provide additional benefit in glycemic control.
- Foods containing sucrose can be used in the meal plan in a way that the CH amount does not exceed 10% of the daily energy requirement instead of an equivalent food, if it is added to the meal plan without a replacement, the dose of insulin should be adjusted. It should also be remembered that excessive energy intake should be avoided.
- Fructose is found naturally in fruits and may provide better glycemic control compared to consuming sucrose or starch at equivalent calories. There is no negative effect on triglyceride levels as long as the consumption of fructose naturally found in fruits does not exceed 12% of daily energy.
- Fiber consumption should be supported, but it is not necessary to advise individuals with diabetes to consume more fiber than the recommended amounts (14 g / 1000 kcal/day, 7-13 g soluble fiber) for the general population.
- Individuals with diabetes should avoid or limit the consumption of beverages sweetened with sugar (calorie-containing sweeteners such as sucrose or high-

fructose corn syrup) to reduce the risk of increased body weight and worsening of the cardiometabolic risk profile [40].

Fat and cholesterol:

The type of fat consumed in the diet and how much it is consumed are of great importance for metabolic control and the development of complications. Reducing dietary saturated fat and cholesterol intake is of great importance in achieving the goal of keeping LDL cholesterol below 100 mg/dl [23].

- Evidence associated with total fat intake ideal for the diabetic individual is controversial. Goals should be individualized.
- The type of fat consumed is more important than how much it is consumed. Recommendations for intake of saturated fat, cholesterol, and trans-fat are the same for those without diabetes.
- In individuals with type 2 diabetes, the Mediterranean diet, a diet rich in monounsaturated fatty acids, may have an impact on glycemic control, cardiovascular risks, and therefore a low-fat, high-carbohydrate diet may be recommended as an alternative.
- As recommended for individuals without diabetes, foods containing long-chain n-3 fatty acids (EPA and DHA) and n-3 linolenic acid should be increased, taking into account their beneficial effect on lipoproteins and their preventive effects on heart disease.
- Evidence does not support the routine recommendation of n-3 (EPA and DHA) supplementation to prevent or treat cardiovascular disorders in individuals with diabetes.
- Diabetic individuals are recommended to eat fish at least 2 times a week (2 servings) as recommended for individuals without diabetes.
- For diabetic individuals with dyslipidemia, consuming 1.6-3 g / day herbal stanol or sterol may be effective in taking total and LDL cholesterol levels.
- Saturated fat intake should be limited to less than 7% of total calories.
- Trans fat intake should be greatly reduced due to its effect of decreasing LDL-cholesterol level and increasing HDL cholesterol level.
- Daily cholesterol intake should be less than 200 mg in diabetic patients.

- Consuming fish at least twice a week provides omega-3 (n-3) polyunsaturated fatty acids and this amount should be recommended. [40]

Protein:

- Evidence regarding the recommendation of an idealized amount of protein intake is controversial as it is effective in the development/control of 1 or more than 1 cardiovascular risk indicator in individuals with diabetes (when there is no evidence of chronic kidney disease) and improves glycemic control.
- Protein intake of <0.8-1.0 g / kg is not recommended in diabetic individuals and diabetic individuals with diabetes-related kidney disease (persistent albuminuria ≥ 30 mg / 24 hours). A further reduction in protein intake does not change the course of the decrease in GFR, nor does it improve cardiovascular risk indicators.
- In individuals with type 2 diabetes, digestion of proteins can increase insulin response without increasing blood glucose concentration. Therefore, proteins should not be used in acute hypoglycemia or the treatment of nocturnal hypoglycemia.
- High protein diets are not recommended for weight loss. The effect of protein intake of more than 20% of energy on diabetes treatment and complications is unknown. These types of diets can provide weight loss and improve glycemia in the short term. However, these benefits are not provided in the long term. In addition, an increase in protein intake also increases saturated fat intake.
- It is recommended that 15-20% (0.8-1 g / kg/day) of daily energy is met from proteins in the general society.
- The effect of proteins on blood glucose levels in patients with type 1 diabetes is not entirely clear.
- There is insufficient evidence to support the positive aspects of using cinnamon or other herbal supplements that are thought to regulate blood sugar in the treatment of diabetes [23].

Vitamin:

- Vitamin C has been reported to help lower high blood sugar levels in Type 2 diabetes patients. Research led by Glenn Wadley from Deakin University in

Australia showed that vitamin C supplements approximately 10 times the amount required during the day reduced both high blood sugar levels and blood pressure in Type 2 diabetes patients. Wadley said that vitamin C lowers the spike in blood sugar after meals by 36 percent in Type 2 diabetic patients, which means almost 3 hours less hyperglycemia per day in patients.
Pointing out that hyperglycemia is also a risk factor for cardiovascular disease, Wadley said, "We also discovered that after taking vitamin C supplements, the rate of people with hypertension dropped by half." said. [42]

- Vitamin C is not a stored vitamin type. For this reason, the number of vitamins needed daily should be taken regularly. The amount needed per day; is 90 mg for men over the age of 20 and 75 mg for women. These values increase to 85 mg in pregnant women and 120 mg in breastfeeding mothers. Although it varies according to age, it will be beneficial to take an average of 50 mg of vitamin C in children.
- In foods, vitamin A is found as retinol and vitamin A precursor carotene. The daily requirement is 1000 mcg for adult men and 800 mcg for women.

Energy:

- The unit used to measure the amount of energy in food is the calorie. The human body gets its energy mainly from carbohydrates, proteins, and fats. Calories are also referred to as macronutrients as they are present in large amounts in the diet. Unlike other nutrients such as trace elements or vitamins, macronutrients contain energy. Also, another source of energy is alcohol. The energy in food is also known as the 'calorific value' and is measured in units of calories or joules. Speaking of calories, it means kilocalories (1000 calories). On the other hand, macronutrients have the different calorie content. The kilocalories per gram of foods that provide energy to the body are as follows.

Carbohydrates: 4 kilocalories per gram

Proteins: 4 kilocalories per gram

Fats: 9 kilocalories per gram

- How many calories a person is allowed to consume per day depends on gender, age, and height. Factors such as regular exercise, sports, and work play a role. After all, an employee on a construction site needs much more energy than an employee in the office. The body needs 70% of the supplied amount for basal metabolic rate. The technical term for this is basal metabolic rate. The amount of energy the body spends at rest is expressed as basal metabolic rate. Basal metabolic rate ensures that all vital functions are maintained. Many people become overweight by eating well above their daily calorie needs. Daily calorie needs vary from person to person.
- Calorie intake should not fall below 1,200 a day in women or 1,500 a day in men, except under the supervision of a health professional. Eating too few calories can endanger your health by depriving you of needed nutrients.[42]

Micronutrients and Herbal Supplements in Diabetes Treatment:

- The dietician should ensure that the levels of vitamins and minerals recommended in the diet are met with the meal plan.
- Unless there are signs of deficiency, there is no clear evidence to suggest vitamin and mineral supplements to individuals with diabetes as in the general population.
- Routine supplementation of antioxidants such as Vitamins E, C, and Carotene is not recommended, since there is insufficient evidence regarding the safety and efficiency of its long-term use.
- The benefit of micronutrient supplements such as magnesium, vitamin D, chromium in diabetic or obese individuals has not been proven and therefore not recommended. [23].

Salt:

- The consumption of <2300 mg/day sodium (5800 mg table salt) recommended for the general population is also suitable for individuals with diabetes.
- Additional reduction in sodium intake in diabetic individuals with hypertension should be made according to the individual [43].

Nutritional Therapy in Type 2 DM:

- To improve glycemia, dyslipidemia, and BP values, type 2 diabetes patients should be supported to reduce their energy intake, saturated and trans fats, cholesterol also sodium, and to increase their physical activity.
- Main and snack times and meal content should be similar throughout the day.
- PG monitoring examines whether adjustments to foods and meals are sufficient to achieve target blood glucose levels or if drug therapy is combined with MNP.

Number and Distribution of Meals:

Studies show that people with diabetes can improve glycemic control through weight loss. The success of this improvement can be achieved by regulating the food intake intervals. It has been found that it is beneficial to distribute the foods throughout the day instead of consuming 2-3 meals. Although insulin takes longer to lower blood glucose due to the delay in acute or 1st phase insulin release, sufficient insulin can be produced in type 2 diabetics. If meals are distributed at 4-5 hour intervals, pre-meal blood glucose values may be at acceptable levels to maximize endogenous insulin secretion. Frequent meals are more suitable for endogenous insulin production. Individual blood glucose monitoring helps determine the ideal meal interval and amount [13].

Meal Planning Methods Used in MNP:

People with diabetes are taught how to plan meals in nutrition education. For this, the dietician can use different methods and educational tools such as change lists, nutrition pyramid, plate model, 1st level of carbohydrate counting, taking into account the individual's lifestyle, education level, and application skills. The plate method is a method that is used visually to explain the principles of healthy nutrition, limit carbohydrate intake, and provide information in a short time. Diabetes patients with a high frequency of eating outside the home, having difficulty in applying other methods, low education level, high protein and carbohydrate intake in food consumption, or a plaque model with a newly diagnosed diabetes may be preferred. (Figure 2.1) [28].

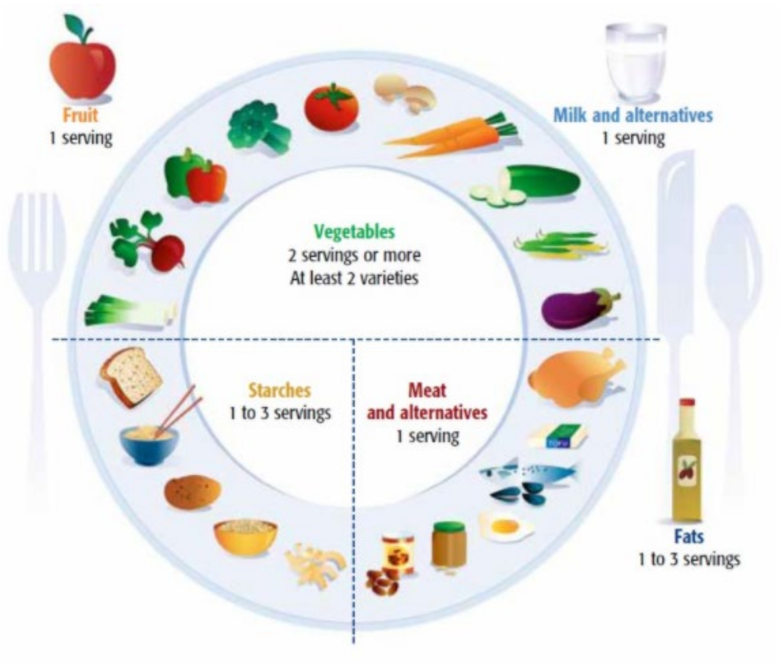

Figure 2.1 Plate Model

Nutrition Education of Individuals with Diabetes and Priority Issues in Education:

The newest and most effective method of treating chronic diseases is to educate the patient about the disease. Education of diabetic individuals in the early 1900's; started by teaching patients to control their sugar in the urine. In 1918, Dr. Eliot P. Joslin's "Joslin Diabetes Handbook" is the first educational material prepared to help diabetic patients live with their diseases. The first diabetes education program Dr. It was implemented by Rome in Portugal. In the following years, various studies have been conducted on this subject. It has been stated that diabetic individuals, who are generally trained, control their diabetes and have fewer complications. Diabetes education is conducted by a diabetes team. To provide an effective diabetes treatment, diabetes centers should be developed and the diabetes team, individuals with diabetes, and their families should be educated [44].

2.3 Findings

Literature about menu planning for diabetics showed that no study takes care of carbohydrate consumption which is an essential issue for diabetic patients. Studies also are lack considering recommendations as mentioned below [45].

- Carbohydrate-containing foods, beverages, and endogenous/exogenous insulin are the main determinants of postprandial glucose control. It should be known that whole grains, starchy vegetables, fruit, milk, dairy products (except cheese), vegetables, and sugar contain carbohydrates.

- When foods containing carbohydrates are to be consumed, consumption of high-fiber, nutritious carbohydrate foods should be preferred instead of processed/packaged foods containing salt, fat, sugar. These foods provide vitamins, minerals, and other healthy elements as well as do not contain fat, sugar, and refined carbohydrates, and provide less energy.
- Portion control should be recommended to reduce and manage body weight.
- Drinks flavored with sugar and high fructose corn syrup should not be preferred.
- Foods containing unsaturated fats (oils) should be preferred instead of foods containing saturated fat and trans-fat.
- Low-fat ones should be preferred instead of those with high-fat content to meet the need for animal-derived protein.
- Since the evidence is insufficient, vitamin and mineral supplements, herbal products, and cinnamon are not recommended for diabetes treatment.
- Sodium intake should be 2300 mg per day.
- Medical treatment should be associated with food intake.

CHAPTER III

PROBLEM DEFINITION

The main purpose of the study is to generate a one-month diet plan for diabetic patients by considering different factors affecting their health issues. The meals are selected from a proposed list of 4078 kinds of food options; while keeping different nutrients above the minimum and below the maximum limits specified for diabetic patients, a minimum cost menu would be chosen, the model objective is to minimize total monthly carbohydrate consumption.

3.1 Constructing Menu

The first step is to create the menu list. To do this, The FNDDS 2017-2018, the ninth version released this food list has been reviewed and this menu list will be used with some changes. The USDA Food and Nutrient Database for Dietary Studies (FNDDS) converts foods and beverages consumed in What We Eat in America (WWEIA), National Health and Nutrition Examination Survey (NHANES) into gram amounts and determines their nutrient values.[46] The initial ingredient information will determine some of the nutritional values for foods such as carbohydrate values, saturated fat, fiber, and salt. It has been observed that many studies such as Koç (2001) are not interested in these values, which are very important for a diabetic diet. The menu will be given in English names as specified in the WHO nutritional ingredients list. Every food will be coded. In this study, 4078 kinds of food; 1848 main meals, 224 soups, 471 fish foods, 460 breakfasts, 1075 garnitures, drinks, vegetables, and desserts were used and there are meal options for 5 meals to be used for 28 days.[47]

3.2 Model Explanation and Mathematical Formulation

3.2.1 Objectives and Decision Variables

The model proposes a 28-day diet plan by minimizing monthly carbohydrate consumption without exceeding the minimum wage budget of the diabetic individual.

Decision Variables: Foods to be consumed at every daily meal and snack foods. Units of variables, daily calorie requirement, calorie (kcal); carbohydrate requirement, fiber requirement, sugar requirement, saturated fat requirement, gram (g); cholesterol requirement, salt requirement, and vitamin c requirement, milligrams (mg); A vitamin requirement is microgram (mcg).

Objective: Minimizing carbohydrate consumption in grams per month.

3.2.2 Overall Review of the Constraints

Constraints will be constructed according to the recommendations in Section 2. The proposed menu should provide necessary nutritive values for a diabetic patient and also the sequence will be ensured.
Nutritive constraints can be summarized as below;

- Daily carbohydrates should not be below 165 g. (%55 of the total daily energy)
- Fiber consumption should be more than 14 g/day.
- Energy from fructose from natural fruits should be below %12 of daily calories.
- Cholesterol intake should be below 200 mg/day
- Energy from saturated fat should be below %7 of daily calories.
- Energy from protein should be below %15 daily calories.
- Sodium consumption should be below 2300 mg/day.
- Vitamin consumption should be the same as the general population for diabetic patients; The daily requirement for vitamin A is 1000 mcg for adult men and 800 mcg for women. The amount of vitamin C to be taken daily is usually 75 mg for women and 90 mg for men.
- The patient has to consume something every day at all meals.
- The patient should eat only one of the main meals in a month (excluding breakfast and snacks).

3.2.3 The Model, Decision Variables, and the Parameters

Notation of the mathematical model is as stated below;

i = Food indices (i =1,…,3829)

j = Meal indices (j=1,…,5)

k = Day of the month (1,...,28)

l = Side foods indices (3830,…,4078)

Decision Variables

$$\begin{cases} x_{ijk} = 1 \;\; If\ i.food\ is\ consumed\ in\ j.meal\ on\ day\ k \\ x_{ijk} = \;\; 0 \;\; If\ i.food\ is\ not\ consumed\ in\ j.meal\ \ on\ day\ k \end{cases}$$

$$\begin{cases} y_{ljk} = 1 \;\; If\ l\ index\ beverage, salad, etc.\ is\ consumed\ in\ j.meal\ on\ day\ k \\ y_{ljk} = 1 \;\; If\ l\ index\ beverage, salad, etc.\ is\ not\ consumed\ in\ j.meal\ on\ day\ k \end{cases}$$

Parameters

e = Daily energy requirement - Minimum daily calorie requirement, 1200 cal.

c = Daily carbohydrate requirement - Minimum daily carbohydrate requirement, 165 g

f = Daily fiber requirement - Minimum daily fiber requirement, 14 g

fr = Daily sugar requirement - Should be below 25 grams.

ct = Daily cholesterol requirement - Maximum daily intake should be below 200 mg

esy = Daily saturated fat requirement - Maximum daily intake should be below %7 of daily calories.

ep = Daily protein requirement - Maximum daily intake should be below %15 of daily calories.

s = Daily salt requirement - Maximum daily intake should be below 2300 mg/day.

a = Daily A vitamin requirement - Minimum daily A vitamin 900 mcg

v = Daily C vitamin requirement - Minimum daily C vitamin 90 mg

e_i = *Energy value of the i. food*

c_i = *Carbohydrate Value of Main Food*

cp_l = *Carbohydrates Value of Side Food*

f_i = *Fiber of Main Food*

fp_l = *Fiber Value of Side Food*

fr_i = *Sugar Value of Main Meal*

frp_l = *Sugar Value of Side Food*

ct_i = *Cholesterol Value of Main Meal*

ctp_l = *Cholesterol Value of Side Food*

Esy_i = *Energy Value of Saturated Fat for Main Meal*

$Esyp_l$ = *Energy Value of Saturated Fat for Side Food*

Ep_i = *Protein Energy for Main Meal*

Epp_l = *Protein Energy for Side Food*

S_i = *Sodium Value of Main Meals*

Sp_l = *Sodium Value of Side Food*

A_i = *Vitamin A Value of Main Meal*

Ap_l = *Vitamin A Value of Side Food*

V_i = *Vitamin C Value of Main Meal*

Vp_l = *Vitamin C Value of Side Food*

$Cost_i$ = *Price Value of Main Meal*

$Cost_l$ = *Price Value of Side Food*

The objective function is to minimize the daily carbohydrate intake for a low-carb diet for Diabetes, which is considered as an alternative nutritional therapy and can help you manage your blood sugar levels, and is shown as follows;

$$\text{Objective} \quad \min z = \sum_i \sum_j \sum_k x_{ijk} * c_i + \sum_l \sum_j \sum_k y_{ljk} * cp_l \qquad \text{(Eq.1)}$$

The number of carbohydrates consumed per day should exceed the minimum limit of 130 grams for a healthy person; the corresponding restriction is as follows;

$$\sum_i \sum_j x_{ijk} * C_i + \sum_l \sum_j y_{ljk} * cp_l \geq 130 \quad \forall k \tag{Eq.2}$$

Since available evidence suggests that high-fiber diets and soluble fiber supplements, especially of the soluble type, may provide some improvement in carbohydrate metabolism, the amount of fiber to be consumed per day should exceed the minimum limit of 14 grams, with the corresponding restriction as follows:

$$\sum_i \sum_j x_{ijk} * f_i + \sum_l \sum_j y_{ljk} * fp_l \geq 14 \quad \forall k \tag{Eq.3}$$

The daily amount of consumed sugar should not exceed the minimum limit of 25 grams to reduce the negative effects of high sugar consumption. The constraint that defines it is as follows:

$$\sum_i \sum_j x_{ijk} * fr_i + \sum_l \sum_j y_{ljk} * frp_l \leq 25 \quad \forall k \tag{Eq.4}$$

HDL cholesterol is what some experts call "good" cholesterol, while LDL cholesterol is what they refer to as "bad" cholesterol. Diabetes tends to lower "good" cholesterol levels and raise triglycerides and "bad" cholesterol levels, which increases the risk for heart disease and stroke. This condition is called diabetic dyslipidemia. Studies show a link between insulin resistance, which is a precursor to Type 2 diabetes, and diabetic dyslipidemia, atherosclerosis, and blood vessel disease. For these reasons, the daily cholesterol intake should be below 200 mg, and the restriction that limits the total cholesterol contained in foods is as follows:

$$\sum_i \sum_j x_{ijk} * ct_i + \sum_l \sum_j y_{ljk} * ctp_l \leq 200 \quad \forall k \tag{Eq.5}$$

To further reduce the risk of heart disease and diabetes, energy from saturated fat should be less than 7% of total daily calories in high-risk groups. The constraint involving this calculation is as follows:

$$\sum_i \sum_j x_{ijk} * Esy_i + \sum_l \sum_j y_{ljk} * Esyp_l \leq \left(\sum_i \sum_j x_{ijk} * cl_i + \sum_l \sum_j y_{ljk} * clp_l\right) * 0{,}07 \quad \forall k \tag{Eq.6}$$

The energy from daily protein should be below 15% of total daily calories, its corresponding constraint is as follows:

$$\sum_i \sum_j x_{ijk} * Ep_i + \sum_l \sum_j y_{ljk} * Epp_l \leq (\sum_i \sum_j x_{ijk} * cl_i + \sum_l \sum_j y_{ljk} * cp_l) * 0{,}15 \quad \forall k \qquad \text{(Eq.7)}$$

The daily sodium intake should be below 2300 mg, its corresponding constraint is as follows:

$$\sum_i \sum_j x_{ijk} * S_i + \sum_l \sum_j y_{ljk} * Sp_l \leq 2300 \quad \forall k \qquad \text{(Eq.8)}$$

Epidemiological studies have shown that the consumption of vegetables and fruits rich in antioxidants such as vitamins A, E, and C reduces the risk of developing diabetes. The daily intake of vitamins should be the same as the general population for diabetics. Therefore, the minimum intake of vitamin A is 900 mcg, and vitamin C is 90 mg.

$$\sum_i \sum_j x_{ijk} * a_i + \sum_l \sum_j y_{ljk} * ap_l \geq 900 \quad \forall k \qquad \text{(Eq.9)}$$

$$\sum_i \sum_j x_{ijk} * V_i + \sum_l \sum_j y_{ljk} * Vp_l \geq 90 \quad \forall k \qquad \text{(Eq.10)}$$

The constraint providing the choice of meals for each cost constraint is as follows ($7.25 per hour and $1305 minimum wage based on maximum working time, and an individual's monthly spending wage of $200 on average).

$$\sum_i \sum_j \sum_k x_{ijk} * cost_i + \sum_l \sum_j \sum_k y_{ljk} * costt_l \leq 200 \quad \forall k \qquad \text{(Eq.11)}$$

The following constraint provides us with the following information: The patient has to consume something at all meals every day.

$$\sum_{i \in breakfast} x_{ijk} \geq 1 \quad \forall k, j = 1 \qquad \text{(Eq.12)}$$

$$\sum_{i \in snack} x_{ijk} \geq 1 \quad \forall k, j = 2 \qquad \text{(Eq.13)}$$

$$\sum_{i \in lunch} x_{ijk} \geq 1 \quad \forall k, j = 3 \qquad \text{(Eq.14)}$$

$$\sum_{i \in snack2} x_{ijk} \geq 1 \quad \forall k, j = 4 \qquad \text{(Eq.15)}$$

$$\sum_{i \in dinner} x_{ijk} \geq 1 \quad \forall k, j = 5 \qquad \text{(Eq.16)}$$

$$\sum_{j=3,5} \sum_k x_{ijk} \leq 1 \quad \forall i \qquad \text{(Eq.17)}$$

The next restriction allows them to eat extra with each main dish (Snack foods are coded with 3 and 5):

$$y_{ljk} \leq 1 \;\; j = 3,5$$

$$y_{ljk} = 0 \;\; j = 1,2,4 \qquad \text{(Eq.18)}$$

3.3 Validation of the Model

'The solution satisfies tolerances' after mixed integer programming model calculations. If there is a solution that satisfies all the constraints, a linear program is feasible, a suitable solution can be constructed. Integer programming is used to solve the proposed model. The solution summary and menu plan can be seen in Tables 3.1 to 3.12 and Chapter 4.

Table 3.1 Menu Results 1

2 DAYS				
1	Breakfast: Egg, whole, fried no added fat, Egg, whole, fried with olive oil, Egg casserole with bread, cheese, milk and meat, Snack: Pine nuts Lunch: Codfish salad, Puerto Rican style, Serenata, Pasta, gluten-free, Barley, NS as to fat Snack: Strawberries, raw, Carrots, canned, reduced sodium, cooked with oil Dinner: Shirataki rice, white, with dark green vegetables, no added fat, Spinach, canned, cooked with oil	2	Breakfast: Egg, white, cooked, no added fat, Egg, whole, fried with olive oil, Egg casserole with bread, cheese, milk and meat, Egg white omelet, scrambled, or fried, made with oil Snack: Crackers, Lemon, raw Lunch: Seafood garden salad with seafood, lettuce, vegetables excluding tomato and carrots, Spinach, canned, cooked with oil Snack: Hazelnuts, Crackers, Lemon, raw Dinner: Shirataki rice, white, with dark green vegetables, no added fat	MENU RESULTS Daily energy requirement, Minimum 1200 kcal Day 1 = 2379 kcal Day 2 = 2404 kcal Daily carbohydrate - Minimum daily fiber requirement, 165 g(%55 of daily calories) Day 1,2 = 165 g Daily fiber requirement - Minimum daily fiber requirement, 14 g Day 1 = 25,8 g Day 2 = 29,9 g Daily sugar requirement - Should be below 25 grams. Day 1 = 24,53 g Day 2 = 20,15 g Cholesterol requirement - Maximum daily intake should be below 200 mg Day 1 = 19 mg Day 2 = 112 mg Daily salt requirement - Maximum daily intake should be below 2300 mg/day. Day 1 = 2284 mg/day Day 2 = 2111 mg/day Daily A vitamin requirement - Minimum daily A vitamin 900 mcg Day 1 = 1556 mg/day Day 2 = 1562 mg/day Daily C vitamin requirement- Minimum daily C vitamin 90 mg Day 1 = 94,5 mg/day Day 2 = 113,9 mg/day · Presolve time: 1.953 sec · Ram: 20 mb · Cost = 101,204 $

Table 3.2 Menu Results 2

3 DAYS							
1	Breakfast: Egg, white, cooked, no added fat, Egg, white, cooked, fat added Snack: Pine nuts, Carrots, frozen, cooked, no added fat Lunch: Shirataki rice Pilav, white, with dark green vegetables, fat added Snack: Almonds, Pecans, unsalted, Strawberries, raw, Carrots, canned, reduced sodium, cooked with oil Dinner: Seafood garden salad with seafood, lettuce, vegetables excluding tomato and carrots	2	Breakfast: Egg, white, cooked, no added fat, Egg, white, cooked, fat added, Egg casserole with bread, cheese, milk, and meat Snack: Crackers, Carrots, frozen, cooked, no added fat Lunch: Shirataki rice Pilav, white, with dark green vegetables, fat added Snack: Pecans, unsalted Dinner: Long Shirataki rice noodles, made from mung beans, cooked, Spinach, fresh, cooked, fat added, NS as to the fat type	3	Breakfast: Egg, white, cooked, no added fat, Egg casserole with bread, cheese, milk and meat Snack: Almonds, lightly salted, Lemon, raw Lunch: Spinach, canned, cooked, no added fat Snack: Pecans Dinner: Spinach, fresh, cooked, fat added, NS as to fat type, Shirataki rice Pilav, white, with dark green vegetables, fat added	MENU RESULTS	
						Daily energy requirement, Minimum 1200 kcal Day 1 = 2203 kcal Day 2 = 2429 kcal Day 3 = 2090 kcal Daily carbohydrate - Minimum daily fiber requirement, 165 g (%55 of daily calories) Day 1,2,3 = 165 g Daily fiber requirement - Minimum daily fiber requirement, 14 g Day 1 = 29,4 g Day 2 = 23,1 g Day 3 = 44,3 g Daily sugar requirement - Should be below 25 grams. Day 1 = 23,33 g/day Day 2 = 20,84 g/day Day 3 = 20,59 g/day Cholesterol requirement - Maximum daily intake should be below 200 mg Day 1 = 4 mg/day Day 2 = 173 mg/day Day 3 = 106 mg/day	Daily salt requirement - Maximum daily intake should be below 2300 mg/day. Day 1 = 1536 mg/day Day 2 = 1994 mg/day Day 3 = 2229 mg/day Daily A vitamin requirement - Minimum daily A vitamin 1000 mcg Day 1 = 1843 mg/day Day 2 = 1797 mg/day Day 3= 1043 mg/day Daily C vitamin requirement- Minimum daily C vitamin 90 mg Day 1 = 92,100 mg/day Day 2 = 117,500 mg/day Day 3 = 96,300 mg/day · Presolve time: : 2.700 sec · Ram: 9 mb · Cost = $119,404

Table 3.3 Menu Results 3

5 DAYS											
1	Breakfast: Egg, white, cooked, no added fat, Egg casserole with bread, cheese, milk, and meat Snack: Pine nuts, Crackers, Strawberries, raw Lunch: Carrots, fresh, cooked, no added fat, Carrots, canned, reduced sodium, cooked with oil Snack: Crackers Dinner: Shirataki rice, white, with carrots, dark green vegetables, and tomatoes and/or tomato-based sauce, no added fat, Spinach, fresh, cooked with oil	2	Breakfast: Egg white omelet, scrambled, or fried, made with oil, Muffin, English, wheat bran Snack: Pecans, unsalted, Lime, raw, Carrots, fresh, cooked, no added fat Lunch: Shirataki rice, white, with carrots, dark green vegetables, and tomatoes and/or tomato-based sauce, no added fat Snack: Lemon, raw Dinner: Spinach, frozen, cooked, no added fat excluding tomato and carrots, Spinach, canned, cooked with oil Snack: Hazelnuts, Crackers, Lemon, raw Dinner: Shirataki rice, white, with dark green vegetables, no added fat	3	Breakfast: Cheese, Bread, wheat or cracked wheat, reduced-calorie and/or high fiber, toasted Snack: Breadsticks, hard, reduced-sodium Lunch: Spinach, fresh, cooked, fat added, NS as to the fat type Snack: Pine nuts, Lemon, raw, Strawberries, raw, Carrots, canned, reduced sodium, cooked with oil Dinner: Crab salad, Spinach, canned, cooked, no added fat	4	Breakfast: Egg, white, cooked, no added fat, Egg white omelet, scrambled, or fried, made with margarine Snack: Pecans, NFS, Crackers, Carrots, frozen, cooked, no added fat Lunch: Ravioli, cheese, and spinach-filled, no sauce Snack: Carrots, frozen, cooked, no added fat Lunch: Shirataki rice Pilav, white, with dark green vegetables, fat added Snack: Pecans, unsalted Dinner: Long Shirataki rice noodles, made from mung beans, cooked, Spinach, fresh, cooked, fat added, NS as to the fat type	5	Breakfast: Egg, white, cooked, no added fat, Egg, white, cooked, fat added, Waffle, fruit, from frozen Snack: Hazelnuts, Crackers, Strawberries, raw Lunch: Romaine lettuce, raw, Stew, NFS Snack: Strawberries, raw Dinner: Green bean casserole	MENU RESULTS	
										Daily energy requirement, Minimum 1200 kcal Day 1 = 2375 kcal Day 2 = 1493 kcal Day 3 = 1704 kcal Day 4 =2335 kcal Day 5 =1635 kcal Daily carbohydrate - Minimum daily fiber requirement, 165 mg(%55 of daily calories) Day 1,2,3,4,5= 165 g Daily fiber requirement - Minimum daily fiber requirement, 14 g Day 1 = 20,5 g Day 2 = 38,9 g Day 3 = 29,8 g Day 4 = 27,7 g Day 5 = 22 g Daily sugar requirement - Should be below 25 grams. Day 1 = 21,33 g Day 2 = 21,53 g Day 3 = 21,25 g Day 4 = 23,29 g Day 5 = 21,75 g Cholesterol requirement - Maximum daily intake should be below 200 mg Day 1 = 107 mg Day 2 = 0 mg Day 3 = 60 mg Day 4 = 83 mg Day 5 = 20 mg	Daily salt requirement - Maximum daily intake should be below 2300 mg/day. Day 1 = 1325 mg Day 2 = 1733 mg Day 3 = 1567 mg Day 4 = 2016 mg Day 5 = 1686 mg Daily A vitamin requirement - Minimum daily A vitamin 1000 mcg Day 1 = 1126 mcg Day 2 = 1503 mcg Day 3 = 1564 mcg Day 4 = 1933 mcg Day 5 = 1418 mcg Daily C vitamin requirement- Minimum daily C vitamin 90 mg Day 1 = 99,8 mg Day 2 = 99 mg Day 3 = 115,4 mg Day 4 = 105,2 mg Day 5 = 135,3 mg · Presolve time: 2.844 sec · Ram: 42 mb · Cost = $108,819

Table 3.4 Monthly Menu Results

Monthly Sample Diet Plan						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
1 Breakfast: Muffin, English, rye Snack: Popcorn, microwave, kettle corn Lunch: Spinach, canned, cooked with butter or margarine Snack: Breakfast tart, low fat, Strawberries, raw Dinner: Quail, cooked, Spinach, fresh, cooked, no added fat	2 Breakfast: Cheese, Bread, Cuban Snack: Melba toast Lunch: Beef and vegetables including carrots, broccoli, and/or dark-green leafy; no potatoes, gravy Snack: Pine nuts, Papaya, raw, Carrots, canned, reduced sodium, cooked, no added fat Dinner: Spinach, raw	3 Breakfast: Cheese, Bread, french or Vienna, whole wheat, Bread, pumpernickel Snack: Pecans, unsalted, Papaya, raw, Blackberries, raw Lunch: Veal cutlet or steak, ns as to cooking method, lean only eaten Snack: Carrots, frozen, cooked, no added fat, Carrots, canned, cooked with oil Dinner: Sweet potato tots, from frozen, baked	4 Breakfast: Egg white omelet, scrambled, or fried, made with butter Snack: Lime, raw Lunch: Chicken, NS as to part, baked, broiled, or roasted, skin not eaten, Yuca fries Snack: Pecans, salted, Crackers, water, Carrots, frozen, cooked with oil, Papaya, raw Dinner: Rice, brown, with gravy, no added fat	5 Breakfast: Egg white omelet, scrambled, or fried, made with oil Snack: Flax seeds, Chia seeds, Strawberries, raw, Carrots, frozen, cooked, no added fat Lunch: Lamb, shoulder chop, cooked, lean only eaten Snack: Pecans, salted, Crackers, water, Strawberries, raw Dinner: Chicken or turkey and vegetables including carrots, broccoli, and/or dark-green leafy; no potatoes, no sauce	6 Breakfast: Cheese, Bread, reduced-calorie and/or high fiber, white or nfs Snack: Crackers, rice, and nuts, Strawberries, raw Lunch: Shrimp garden salad, shrimp, lettuce, eggs, tomato and/or carrots, other vegetables, no dressing Snack: Pine nuts, Strawberries, frozen, Carrots, frozen, cooked with oil Dinner: Spinach, canned, cooked, no added fat	7 Breakfast: Cheese, Bagel, oat bran Snack: Strawberries, raw, Carrots, frozen, cooked with oil Lunch: Pasta, cooked, Barley, no added fat Snack: Walnuts, excluding honey roasted Dinner: Sweet potato, hash brown, from fast food, Spinach, fresh, cooked with oil

Table 3.4 Monthly Menu Results (Cont.)

Monthly Sample Diet Plan						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
8 Breakfast:Egg white omelet, scrambled, or fried, made with oil Snack: Flax seeds, Strawberries, raw Lunch:Fried broccoli Snack:Popcorn, microwave, kettle corn, light, Carrots, frozen, cooked with oil, Carrots, frozen, cooked with butter Dinner: Rice, brown, with vegetables and gravy, ns as to fat fresh, cooked with oil	9 Breakfast: Cheese, cottage, salted, dry curd, Bread, puri, wheat Snack: Lemon, raw Lunch: Chicken or turkey garden salad, chicken and/or turkey, other vegetables excluding tomato and carrots, no dressing, Pasta, vegetable, cooked, Stuffed pepper, with rice, meatless, Potato, french fries, fast food Snack: Carrots, fresh, cooked, no added fat Dinner: Pasta, whole grain, with a tomato-based sauce and added vegetables, restaurant	10 Breakfast: Oatmeal, instant, plain, made with milk, no added fat Snack: Pine nuts, Cookie, Pizzelle, Strawberries, frozen Lunch: Potato, hash brown, from school lunch Snack:Strawberries, frozen Dinner:Spinach, frozen, cooked, fat added, ns as to fat type, Spinach, frozen, cooked with butter	11 Breakfast: Focaccia, Italian flatbread, plain Snack:Carrots, frozen, cooked with oil Lunch:Macaroni or noodles with cheese and tomato Snack:Pine nuts, Strawberries, raw Dinner:Rice, white, with carrots, dark green vegetables, and tomatoes and/or tomato-based sauce, no added fat, Spanish rice, ns as to fat, Stewed potatoes, Puerto Rican style	12 Breakfast: Egg white omelet, scrambled, or fried, made with oil Snack: Pecans, NFS, Pecans, unroasted, Carrots, raw Lunch: Seafood stew with potatoes and vegetables excluding carrots, broccoli, and dark-green leafy; tomato-based sauce, Rice, white, with dark green vegetables, no added fat Snack: Pretzels, hard, plain, lightly salted, Lime, raw Dinner: Beef stew with potatoes and vegetables excluding carrots, broccoli, and dark-green leafy; tomato-based sauce, Salmon, baked or broiled, made with cooking spray	13 Breakfast: Egg white omelet, scrambled, or fried, made with oil Snack: Breakfast tart, low fat, Lemon, raw, Carrots, raw Lunch: Codfish fritter, Puerto Rican style, Rice, brown, with dark green vegetables, no added fat Snack: Pecans, unsalted, Shrimp and vegetables including carrots, broccoli, and/or dark-green leafy; no potatoes, no sauce Dinner: Shrimp and vegetables including carrots, broccoli, and/or dark-green leafy; no potatoes, no sauce	14 Breakfast:Pancakes, gluten-free, from frozen Snack Pecans, unroasted, Carrots, canned, cooked with oil Lunch: Shrimp shish kabob with vegetables, excluding potatoes, White beans, from dried, no added fat, Couscous, plain, cooked, Spinach, fresh, cooked, fat added, NS as to the fat type Snack:Raspberries, raw, Raspberries, frozen.. Dinner:Rice noodles, cooked

Table 3.4 Monthly Menu Results (Cont.)

Monthly Sample Diet Plan						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
15 Breakfast: Bread, sprouted wheat, toasted Snack:Carrots, frozen, cooked with oil Lunch: Long rice noodles, made from mung beans, cooked, Macaroni or pasta salad, made with Italian dressing, Potato tots, frozen, baked Snack:Walnuts, excluding honey roasted, Grapefruit, raw, Strawberries, raw Dinner: Rice, brown, with carrots, dark green vegetables, and tomatoes and/or tomato-based sauce, no added fat	16 Breakfast: Cheese Injera, Ethiopian bread Snack: Snack mix, Carrots, frozen, cooked with oil Lunch: Chicken breast, fried, coated, skin/coating not eaten, from pre-cooked, Pasta with a tomato-based sauce, meat, and added vegetables, ready-to-heat, Rice, brown, with dark green vegetables and tomatoes and/or tomato-based sauce, no added fat Snack: Pecans, unsalted, Pine nuts, Strawberries, raw Dinner: Spinach, fresh, cooked with butter	17 Breakfast: Cereal (Kellogg's Corn Flakes) Snack: Popcorn, microwave, low sodium, Carrots, frozen, cooked with oil Lunch: Seafood garden salad with seafood, lettuce, vegetables excluding tomato and carrots, no dressing Snack: Pecans, salted Dinner: Chicken breast, baked, broiled, or roasted, skin not eaten, from raw	18 Breakfast:Oatmeal, instant, plain, made with milk, no added fat Snack: Pine nuts, Pretzels, soft, multigrain Lunch: Rice, brown, with carrots and tomatoes and/or tomato-based sauce, ns as to fat Snack: Grapefruit, raw, Lemon, raw Dinner: Potato, french fries, from frozen, fried, Spinach, frozen, cooked with oil	19 Breakfast: Muffin, English, whole grain white Snack: Strawberries, raw, Carrots, frozen, cooked with oil Lunch: Beefsteak, breaded or floured, baked or fried, NS as to fat eaten Snack: Pecans, unsalted, Pretzels, soft, multigrain, Strawberries, raw Dinner: Romaine lettuce, raw, Fried green beans	20 Breakfast: Egg, white, cooked, no added fat, Egg substitute, omelet, scrambled, or fried, no added fat, Bread, black, toasted Snack: Strawberries, raw, Carrots, canned, reduced sodium, cooked with oil Lunch: Rice, white, with carrots and dark green vegetables, fat added, Spinach, canned, cooked with oil Snack: Pecans, unsalted, Blackberries, raw Dinner: Barley, ns as to fat, Quinoa, fat added	21 Breakfast: Cheese, Bread, French or Vienna, toasted Snack: Sesame seeds Lunch: Pasta, gluten-free Snack: Papaya, raw, Strawberries , raw Dinner: Sushi, topped with tuna, Dirty rice

Table 3.4 Monthly Menu Results (Cont.)

Monthly Sample Diet Plan						
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
22 Breakfast: Egg white, omelet, scrambled, or fried, with vegetables, Muffin, English, wheat bran Snack: Breadsticks, hard, gluten-free Berries, nf Lunch: Chicken or turkey fricassee, with sauce, no potatoes, potatoes reported separately, Puerto Rican style: Potato salad, made with mayonnaise Snack: Carrots, raw Dinner: Potato, home fries, with vegetables	23 Breakfast: Cheese, Bread, puri, wheat Snack: Raspberries, raw, Strawberries, raw, Carrots, cooked, from restaurant Lunch: Beef and vegetables including carrots, broccoli, and/or dark-green leafy; no potatoes, no sauce Snack: Creamsicle, light, Crackers, cheese, whole grain Dinner: Cake or pancake made with rice flour and/or dried beans	24 Breakfast: Cheese, Bread, native, water, Puerto Rican style, Bread, puri, wheat Snack:Strawberries, raw Lunch: Potato, hash brown, ready-to-heat Snack: Honeydew melon, raw, Carrots, raw, Carrots, frozen, cooked, no added fat Dinner: Chicken patty, breaded	25 Breakfast: Cheese, cottage, nfs Snack: Strawberries, raw, Carrots, frozen, cooked with oil Lunch: Pink beans, cooked Snack: Popcorn, popped in oil, unbuttered Dinner: Rice, white, with corn, ns as to fat, Rice, white, with dark green vegetables, ns as to fat, Spanish rice, fat added	26 Breakfast, Cheese, Bread, high protein Snack: Pine nuts, Casabe, cassava bread, Carrots, frozen, cooked with oil Lunch: Rice, brown, with carrots and dark green vegetables, no added fat Snack:Strawberries, raw Dinner:Beef, roast, canned	27 Breakfast: Cheese, Bagel, oat bran Snack: Lemon, raw Lunch: Chicken or turkey salad with egg Snack: Cookie, sugar wafer, sugar-free, Strawberries, raw, Carrots, frozen, cooked, no added fat Dinner: Salmon salad, Rice, brown, with carrots, fat added	28 Breakfast: Muffin, English, cheese, Injera, Ethiopian bread Snack: Almonds, unsalted, Lemon, raw, Carrots, frozen, cooked with butter or margarine, Carrots, canned, reduced sodium, cooked, no added fat Lunch: Potato tots, school Snack: Hazelnuts Dinner: Bulgur, NS as to fat Radicchio, raw, Spinach, canned, cooked, fat added, NS as to fat type

It is seen that the menus we obtain in menu planning with carbohydrate minimization are menus that can be applied to real-life and that an individual can be fed easily by giving substitute products with these menus. In the solution, the same group meals were not given on the same day, the next day, or even in the same month, and the meals were diversified as much as possible. In the diet, the menu results of which can be seen above, the menu variety was provided alternately with fish, meat or chicken as the main meal during the week, eggs were consumed intensively at breakfast meals, and even recipes were given with eggs, the menu was enriched. Since it is obvious how important nutrition is for diabetic patients, a good balance of carbohydrates, protein, fiber, and vitamins is provided in all of our menus by providing adequate nutritional content.

Considering the cost of 4078 types of food, a minimum cost menu would be chosen, but it was seen that the solution was provided by the restrictions used for the meals. This could be achieved both in main meals and snacks; especially due to the high diversity of foods, the meals provided the constraints without being repeated. After these constraints were added to the model, they were resolved and one-month menus were obtained for 28 days. While the menus of 2, 3, and 5 days, which are solved initially, provide the optimum solution, the menus of 28 days provide tolerances.

Table 3.5 28 Days Menu Requirement Results

	Daily carbohydrates Min 165 g (%55 of daily calories)	Daily fiber requirement Min 14 g	Daily sugar requirement Max 25 g/day	Daily cholesterol Max 200 mg	Daily salt requirement Max 2300 mg/day.	Daily A vitamin requirement Min 900 microgram (mcg)	Daily C vitamin requirement Min 90 mg
1	198.610	25.300	16.790	90	2233	1385	101.600
2	165.870	18.900	20.850	23	1633	1215	98.200
3	166.790	33.600	23.900	106	2084	1446	95.500
4	169.970	26.800	19.750	130	2202	925	108.300
5	170.510	79.600	22.640	123	2230	1048	131.500
6	165.110	24.800	23.770	124	1613	1477	123.600
7	165.190	37.700	22.560	109	1718	1118	91.400
8	169.540	26.800	19.450	0	1819	1328	90.100
9	165.110	53.100	19.250	15	1811	1726	94.300
10	165.120	22.100	15.930	49	2096	1010	113.700
11	165.150	23.200	24.220	13	946	1398	94.200

Table 3.5 28 Days Menu Requirement Results (Cont.)

12	166.610	17.200	21.180	16	1846	973	93.400
13	165.320	31.000	20.290	112	2086	902	93.900
14	171.160	21.100	18.690	11	1111	1386	91.400
15	165.160	25.200	24.710	0	1547	1004	113.000
16	165.680	30.000	22.480	110	2228	1386	99.600
17	169.640	28.200	21.200	161	2223	1476	103.800
18	168.320	20.700	19.220	7	1244	924	97.200
19	166.370	26.700	21.460	59	1494	1199	130.100
20	165.000	35.200	21.440	0	2165	1191	105.800
21	165.910	23.200	24.860	67	1536	1093	129.800
22	165.610	23.800	18.620	62	2272	924	90.900
23	165.190	30.200	20.630	50	1756	1055	107.700
24	166.270	17.700	24.060	43	1906	1682	91.600
25	170.440	23.100	16.640	15	1544	917	91.000
26	165.020	17.200	17.780	82	1995	916	99.100
27	166.610	29.200	22.470	130	1810	1067	116.200
28	165.230	43.500	24.750	11	1603	1903	96.300

In our study, the results of which we have seen above, we can see that there is a model that can provide a high level of carbohydrate minimization and diversity in all menus. In menu solutions, the mathematical model presents very different menu results each time it is run. While the variety was different and the number of carbohydrates was odd in the 2, 3, and 5-day menus, better results were obtained in the 28-day menu due to the high number of nutrients and the more restrictions. The fact that the amount of cholesterol is significantly low seems to be important for diabetes patients to protect their health. The use of the high amount of vitamin A and high fiber ratio is also supportive in recommending diabetic patients to use this diet. Because these uses are important as stated in the research sections of our thesis. According to research, it shows that the level of carbohydrates can be defeated by consuming only as much as it should be taken, as in the table above. However, given the success of low-carb diets is not only reducing the need for insulin but also reducing the risk of heart disease, the ADA has adjusted its recommendations to support a lower-carb diet.

Table 3.6 Final Solve Report 2 Days

MIP Solution	330 (13901 iterations, 2326 nodes)
Final Solve	330
Best Possible	330
Absolute gap	0
Relative gap	0

S O L V E   S U M M A R Y

MODEL Diet   OBJECTIVE objective
TYPE MIP   DIRECTION MINIMIZE
SOLVER CPLEX   FROM LINE 45617

**** SOLVER STATUS 1 Normal Completion
**** MODEL STATUS 1 Optimal
**** OBJECTIVE VALUE 330.0000

RESOURCE USAGE, LIMIT 38.673 10000000.000
ITERATION COUNT, LIMIT 13901 10000000
IBM ILOG CPLEX Jul 4, 2010 23.5.1 WIN 18414.18495 VS8 x86/MS Windows
Cplex 12.2.0.0, GAMS Link 34
GAMS/Cplex licensed for continuous and discrete problems.
Cplex MIP uses 1 of 4 parallel threads. Change default with option THREADS.
MIP status(101): integer optimal solution
Fixed MIP status(1): optimal
Proven optimal solution.

Table 3.7 Final Solve Report 3 Days

MIP Solution	495 (75372 iterations, 5213 nodes)
Final Solve	495
Best Possible	495
Absolute gap	0
Relative gap	0

S O L V E   S U M M A R Y

MODEL Diet   OBJECTIVE objective
TYPE MIP   DIRECTION MINIMIZE
SOLVER CPLEX   FROM LINE 45619

**** SOLVER STATUS 1 Normal Completion
**** MODEL STATUS 1 Optimal
**** OBJECTIVE VALUE 495.0000

RESOURCE USAGE, LIMIT 81.989 10000000.000
ITERATION COUNT, LIMIT 75372 10000000

IBM ILOG CPLEX Jul 4, 2010 23.5.1 WIN 18414.18495 VS8 x86/MS Windows
Cplex 12.2.0.0, GAMS Link 34
GAMS/Cplex licensed for continuous and discrete problems.
Cplex MIP uses 1 of 4 parallel threads. Change default with option THREADS.
MIP status(101): integer optimal solution
Fixed MIP status(1): optimal
Proven optimal solution.

Table 3.8 Final Solve Report 5 days

MIP Solution	825 (480699 iterations, 110100 nodes)
Final Solve	825
Best Possible	825
Absolute gap	0
Relative gap	0

S O L V E   S U M M A R Y

MODEL Diet   OBJECTIVE objective
TYPE MIP   DIRECTION MINIMIZE
SOLVER CPLEX   FROM LINE 45619

**** SOLVER STATUS 1 Normal Completion
**** MODEL STATUS 1 Optimal
**** OBJECTIVE VALUE 825.0000

RESOURCE USAGE, LIMIT 784.899 10000000.000
ITERATION COUNT, LIMIT 480699 10000000

IBM ILOG CPLEX Jul 4, 2010 23.5.1 WIN 18414.18495 VS8 x86/MS Windows
Cplex 12.2.0.0, GAMS Link 34
GAMS/Cplex licensed for continuous and discrete problems.
Cplex MIP uses 1 of 4 parallel threads. Change default with option THREADS.
MIP status(101): integer optimal solution
Fixed MIP status(1): optimal
Proven optimal solution.

Table 3.9 Final Solve Report

MIP Solution	4700,51 (36771 iterations, 4891 nodes)
Final Solve	4700,51
Best Possible	4620
Absolute gap	80,51
Relative gap	0,017128

S O L V E   S U M M A R Y

MODEL Diet   OBJECTIVE objective
TYPE MIP   DIRECTION MINIMIZE
SOLVER CPLEX   FROM LINE 45617

**** SOLVER STATUS 1 Normal Completion
**** MODEL STATUS 8 Integer Solution
**** OBJECTIVE VALUE 4700.5100

RESOURCE USAGE, LIMIT 496.202 10000000.000
ITERATION COUNT, LIMIT 36771 10000000

IBM ILOG CPLEX Jul 4, 2010 23.5.1 WIN 18414.18495 VS8 x86/MS Windows
Cplex 12.2.0.0, GAMS Link 34
GAMS/Cplex licensed for continuous and discrete problems.

Cplex MIP uses 1 of 4 parallel threads. Change default with option THREADS.
MIP status(102): integer optimal, tolerance
Fixed MIP status(1): optimal
Solution satisfies tolerances.

In diabetes menu planning with carbohydrate minimization, optimum results were found with a relative gap of zero in the first 2, 3 and 5-day menus, while the gap was found to be 0,017 as optimal satisfies due to the many restrictions in the 28-day menu and the package program used, as seen in Table 3.9. The optimum amount of carbohydrates was found to be 4700.51 grams. Constraints are met and menu results give satisfactory results. The menus created with carbohydrate minimization can be recommended to diabetic patients, as they are at a level that will not strain the individual's pocket and meet the necessary nutritional values.

3.4 Statistical Analysis

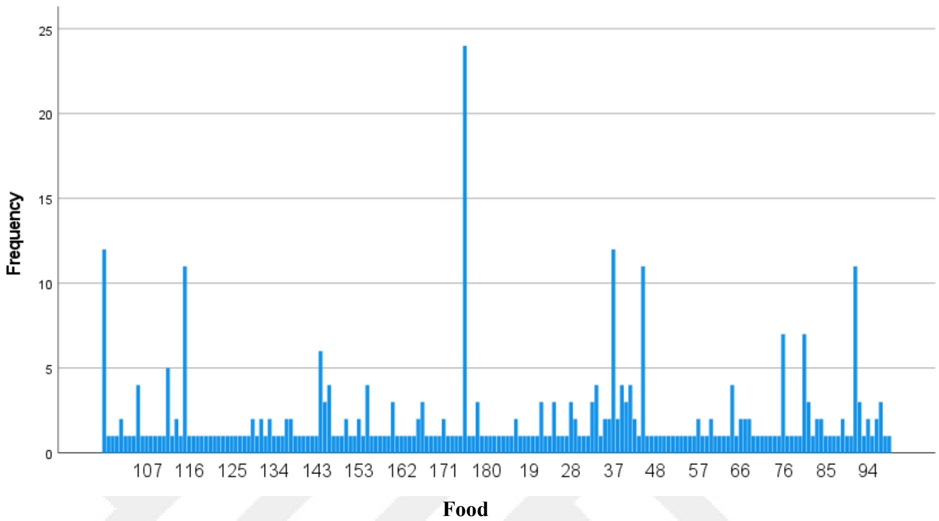

Figure 3.1 Result Frequencies

Frequency analysis of all the data obtained as a result of mathematical modeling and the 40-days food list was performed on IBM SPSS Statistics 27.0.1, variables is the number given to each selected food and the monthly repeat rates of the nutrients are looked at, and it was observed that all foods were repeated with a frequency of 0.003, except for some healthy snack options, and the majority of them were selected only once. In Figure 3.1, the most repeated products in the menu with the highest frequency are almonds and strawberries. This analysis is evidence of the high diversity of the study.

As a next analysis, we compared in the Table 3.10 menu results to see if the results of the Study and the constraints we applied made a difference: " Group 1, Menu planning for diabetics with carbohydrate minimization", " Group 2, Study of the impact of a 24-week Internet-based menu planning program examining pre-and post-intervention changes in body weight, blood pressure, and glycemia among overweight adults with type 2 diabetes."[64] Hypothesis established and Paired Samples T-Test performed on IBM SPSS Statistics 27.0.1. The group names can be seen below.

Group 1: Menu planning for diabetics with carbohydrate minimization	Group 2: Study of the impact of a 24-week Internet-based menu planning program examining pre-and post-intervention changes in body weight, blood pressure, and glycemia among overweight adults with type 2 diabetes.
Carbohydrate 1	Carbohydrate 2
Fat 1	Fat 2
Fiber 1	Fiber 2
Sodium 1	Sodium 2

Table 3.10 Samples of Groups

	Carbohydrate	Fat	Fiber	Sodium
Group 1	198.61	90.00	25.30	2.23
	165.87	23.00	18.90	1.63
	166.79	106.00	33.60	2.08
Group 2	210.80	90.60	21.60	3,10
	219.80	83.20	23.20	2.70
	201.10	96.70	20.30	3.40

Null Hypothesis (H0): There are no significant differences between "Internet-Delivered Menu Plans Among Adults with Type 2 Diabetes Mellitus" and our thesis.
Research Hypothesis (H1): There are significant differences between "Internet-Delivered Menu Plans Among Adults with Type 2 Diabetes Mellitus" and our thesis. (double tail test)

Table 3.11 T-Test Solution Reports

Paired Samples Tests

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Carbohydrate2 - Carbohydrate1	33,47667	20,88247	12,05650	-18,39828	85,35161	2,777	2	0,109

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 2	Fat2 - Fat1	17,16667	37,59526	21,70563	-76,22513	110,55846	0,791	2	0,512

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 3	Fiber2 - Fiber1	-4,23333	8,81211	5,08768	-26,12384	17,65717	-0,832	2	0,493

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Sodium1 - Sodium2	-0,42000	0,60622	0,35000	-1,92593	1,08593	-1,200	2	0,353

As seen in Table 3.11, it is seen that the Significance Value for Pairs 1,2,3, and 4 is greater than 0.05, so H0 is accepted. It can be interpreted that there is no significant difference in carbohydrate, fat, fiber, and sodium values between these two studies. The equation is written as:

H0 Hypothesis (Accepted)
(Carbohydrate/Fat/Fiber/Sodium)1=(Carbohydrate/Fat/Fiber/Sodium)2

H1 hypothesis (Rejected)
(Carbohydrate/Fat/Fiber/Sodium)1≠ (Carbohydrate/Fat/Fiber/Sodium)2

3.5 Cost Analysis

For the Cost Analysis, the daily menu fees were subtracted and the cost levels of the other menus to be derived from the "Menu planning model for diabetes patients with carbohydrate minimization" were estimated. 28 days menu cost was used and One-Sample T-Test was applied.

Null Hypothesis (H0): There is no significant difference between all the menu prices to be selected and the sample menu prices.

Research Hypothesis (H1): There is a significant difference between all the menu prices to be selected and the sample menu prices.

Table 3.12 T-Test Results

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Costs	28	166,9732	4,75023	0,89771

	Test Value = 0					
					Interval of the	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Costs	185,999	27	<0,001	166,97321	165,1313	168,8152

		Standardizer[a]	Point Estimate	Interval	
				Lower	Upper
Costs	Cohen's d	4,75023	35,151	25,816	44,466
	Hedges' correction	4,88748	34,163	25,092	43,218

a. The denominator used in estimating the effect sizes.

H0 was rejected as the significance value was less than 0.05 in Table 3.12. In other words, there is significant difference between the samples taken and the menus to be re-selected. In other words, the menus can be calculated according to nutritional values and can be interpreted as giving various menus within the determined constraints. An average of \$167, 13% of the minimum wage (\$7.25 per hour and \$1305 based on maximum working time). This is an affordable menu even for minimal gains in terms of nutrition.

H0 Hypothesis (Rejected) Sample = New menus to be derived

H1 hypothesis (Accepted) Sample ≠ New menus to be derived

CHAPTER IV

CONCLUSION AND RECOMMENDATIONS

The diabetes menu model with carbohydrate minimization was first tried in fewer days and analyzed separately with optimal results, and as a result of the studies, menus for the last 28 days were obtained. It has been carefully prepared considering the nutritional values that diabetic patients should consume daily and are critical for them. While applying the menus found, the places of the meals can be changed daily, so that diversity can be provided according to the individual's desire, food availability, and cost.

4.1 Obtaining the Menus

The diet model for diabetes patients was first written separately as 2, 3, and 5-day menus in the Gams 23.5.1 package program, and 28-day menus were obtained in the final stage by solving each of them. All restrictions were determined according to the Diet, nutrition, and the prevention of type 2 diabetes resource of the World Health Organization, and the data sets were reduced to 4078 types by extracting the foods that diabetes patients can consume from The USDA Food and Nutrient Database for Dietary Studies (FNDDS).

4.2 Analysis of the Proposed Model and Comparison with Other Models

Creating a diet list for diabetics is very demanding and often complex for dietitians, but forms the basis of working principles; they can prescribe detailed examinations of the relationship between diseases and nutrition routine. At this stage, the mathematical models examined under operations research; In menu planning for diabetes patients, saves both time and cost and find a solution to meet the nutritional needs of the target group and to gain health. Other studies have not been fully successful with the menus they have obtained for diabetics according to the men planning working principle; the cost calculation objective function was made and the daily nutritional values that patients should focus on were not prioritized.

The most important advantage of the developed program is that it offers a menu that minimizes the carbohydrate level, which is critically important for the determined patient group, by complying with the required daily consumption amount. Although the menu variety is at the highest level, the model can be updated with data such as the patient's age and body mass index, and the desired menu list can be accessed instantly. At the same time, it complies with all the recommendations for diabetes patients determined by the World Health Organization within the model.

Since the menu planning rules were not comprehensively included in the model in previous studies, the usability of the created menus is also low. From these studies; In Atlas (1988) and Koç's (2001) models; things to consider in menu planning

Constraints were created only for not having two meals from the same group at the same meal and not repeating the same meals at the next meal or in the day, and no other menu planning rules were mentioned. In Atlas's (1988) study, there was no dietitian as the decision-maker.

The menus obtained with the model were not evaluated for their suitability for menu planning. As a result of this; stuffed zucchini, rice pilaf, string kadayif; dried beans, pastry, tzatziki; menus such as roast meat, noodle soup, and cherry compote have emerged that are not suitable for menu planning. Operations research, which includes mathematical models, requires experts in the relevant fields of the problem to be solved and work together. For this reason, this study, which was carried out as operations research using integer programming from mathematical models; worked with operations analysts and a dietitian served as the decision-maker. Thus, a more effective way to achieve the goals was drawn. Another advantage of the model for mass feeding systems is that the desired number of menus can be obtained with the model. Thus, it is possible to plan not only 28-day menus but much more.

In the model, the annual feeding cost of the menus for one person was $110,125 and below; Although the product variety is high because it is calculated with the minimum calorie value that can be taken, no cost-increasing factor has occurred. For this, as was done in the study, the calorie value can be easily changed according to the individual and with the desired cost, special carbohydrate minimization menus can be obtained for diabetes patients. Due to the cost constraint, the model is at a level and variety that can apply a collective nutrition plan in all kinds of institutions. In this way, lower-cost menus can be made, as well as higher-cost menus can be created.

Although a standard individual with low activity diabetes was selected as the feeding group in the study; when the values in the constraints are changed, the model can be applied to any group. Thus, adequate and balanced nutrition can be provided for each group to be administered. If an individual with more activity or a larger body mass index is to be selected as a group; menu planning will change to meet the needs of the group; to do this, instead of changing all the constraints, the menus can be instantly balanced by changing the recommended values according to the calculation of calories to be taken. The model can be customized by having him choose more fruits, drinks, meat dishes, or fish dishes according to the person or lifestyle.

4.3 Conclusion and Recommendations

Menu planning is the most important component for improving people's health and quality of life. The menu plan for diabetes patients, which was created with integer programming, has become a more advanced and applicable model compared to other studies. It will be very useful to benefit from mathematical models that these patients, who need dietitian support for a lifetime, can access as they wish, both with less cost and without wasting time.

In this period, where we are getting used to the learning of machines and their inclusion in our lives, the menus created can be easily adapted by presenting them to the public through easy-to-use interfaces.

When desired, the desired menus can be easily accessed by taking into account the restrictions such as gender and BMI, for example, by increasing the calorie to 2500 calories, calculating 55% of the carbohydrate amount, and updating other constraints, which shows the flexibility of our model.

This study was planned to create a menu with an integer programming model and a wide variety of menus were presented to diabetic patients. Unlike previous studies, optimally beneficial menus are targeted for patients by using an objective function that minimizes carbohydrates. 28-day menu planning was handled using 20 decision variables and 26 constraints along with diabetic conditions in mathematical planning. Thus, in the study, the errors and inaccuracies experienced in menu planning problems have been eliminated against any situation that may be desired, and the monthly intakes of nutrients have been determined. In the determined model, the optimum solution of the cost has been found.

At the end of the study; it has been realized that a solution to the menu planning problem can be produced with the fuzzy logic method, which is also widely used in the field of operations. In this way, it is thought that menu planning will gain more flexibility by minimizing the deviations from the conditions that constitute a critical place in nutrition, and it is considered that it can be addressed in future studies.

REFERENCES

[1] McCann-Rugg, M., White, G. P., Endres, J. M. (1983). Using goal programming to improve the calculation of diabetic diets. Computers & Operations Research, **10(4),** 365-373.

[2] Kazan, A. (2002). Solving a Balanced Nutrition Problem with Equal Priority Goal Programming Model, Journal of Legislation, Issue: 50 **4(46)**.

[3] Bader, A., Gougeon, R., Joseph, L., Da Costa, D., Dasgupta, K. (2013). Nutritional education through internet-delivered menu plans among adults with type 2 diabetes mellitus: Pilot study. JMIR research protocols, **2(2),** e2525.

[4] TAHA Hamdy A., Operations Reserch An Introduction, Sixth Edition, Macmillan Publishing Company, New York, 1987, s.11

[5] Dictionary, T. T. (1998). Turkish Dictionary 9th edition. Ankara: Turkish Language Association.

[6] Kljusurić, J. G., Tušek, A. J., Valinger, D., Benković, M., & Jurina, T. (2018). Multi-criteria Decision Analysis: Linear and Non-linear Optimization of Aqueous Herbal Extracts. In *Multicriteria Analysis in Agriculture* (pp. 167-184). Springer, Cham.

[7] Reyhan, P., Approach to Balanced and Sufficient Nutrition with Target Programming Method, Science Specialization Thesis, Hacettepe University, Ankara, 1990.

[8] ORAL, H., Menu Planning Through Multiobjective Programming: an Application in the Turkish Army, Yüksek Lisans Tezi, Yeditepe Üniversitesi, İstanbul, 199

[9] Koç, E. (2001). Interactive 0-1 Integer Linear Goal Programming And Its Application To Solving A Diet Problem. Osmangazi University, Institute of Science and Technology, Master Thesis, Eskisehir.

[10] Garille, S. G., Gass, S. I. (2001). Stigler's diet problem revisited. Operations Research, **49(1),** 1-13.

[11] Kazan, A. (2002). Solving a Balanced Nutrition Problem with Equal Priority Goal Programming Model, Journal of Legislation, Issue: 50 **4(46)**.

[12] Valdez-Pena, H., Martinez-Alfaro, H. (2003, October). Menu planning using the exchange diet system. In SMC'03 Conference Proceedings. 2003 IEEE International Conference on Systems, Man and Cybernetics. Conference Theme-System Security and Assurance (Vol. 3, pp. 3044-3049). IEEE.

[13] Kashima, T., Matsumoto, S., Ishii, H. (2009, October). Development of Web-Based Menu Planning Support System and its Solution Using Genetic Algorithm. In AIP Conference Proceedings (Vol. 1174, No. 1, pp. 56-68). American Institute of Physics.

[14] Funabiki, N., Taniguchi, S., Matsushima, Y., Nakanishi, T. (2011, June). A proposal of a menu planning algorithm for two-phase cooking by busy persons. In 2011 International Conference on Complex, Intelligent, and Software Intensive Systems (pp. 668-673). IEEE.

[15] Kljusurić, J. G., Tušek, A. J., Valinger, D., Benković, M., Jurina, T. (2018). Multi-criteria Decision Analysis: Linear and Non-linear Optimization of Aqueous Herbal Extracts. In Multicriteria Analysis in Agriculture (pp. 167-184). Springer, Cham.

[16] Ali, M., Sufahani, S., Ismail, Z. (2016). A new diet scheduling model for Malaysian school children using zero-one optimization approach. Global Journal of Pure and Applied Mathematics, **12(1),** 413-419.

[17] Yulina, S., Hajar, D. (2017, December). Kids Menu Care: An Application for Food Menu Scheduling with Caloric Balance. In Proceedings of the 2017 International Conference on Information Technology (pp. 253-257).

[18] Dhoruri, A., Lestari, D., Ratnasari, E. (2017, August). Menu variations for diabetes mellitus patients using Goal Programming model. In AIP Conference Proceedings (Vol. 1867, No. 1, p. 020015). AIP Publishing LLC.

[19] Marrero, A., Segredo, E., Leon, C. (2019, July). On the automatic planning of healthy and balanced menus. In Proceedings of the Genetic and Evolutionary Computation Conference Companion (pp. 71-72).

[20] Lee, O. A., Sufahani, S. F., Abd Wahab, M. H., Idrus, S. Z. S., Surono, S., Ahmad, A. (2020, September). Computerized integer programming method: menu scheduling for critical illness patients. In IOP Conference Series: Materials Science and Engineering (Vol. 917, No. 1, p. 012057). IOP Publishing.

[21] ATMACA, A. (2012). Diagnostic and follow-up criteria of diabetes mellitus. Journal of Experimental and Clinical Medicine, **29(1s)**, 2-6.

[22] American Diabetes Association.(2)(2015). Standards of medical care in diabetes—2015 abridged for primary care providers. Clinical diabetes: a publication of the American Diabetes Association, **33(2),** 97.

[23] Bozkurt, N., Yıldız, E. (2008). Diabetes mellitus and nutritional therapy. Byasal A. Ankara, Hatiboğlu Publishing House.

[24] Steyn, N. P., Mann, J., Bennett, P. H., Temple, N., Zimmet, P., Tuomilehto, J., Louheranta, A. (2004). Diet, nutrition and the prevention of type 2 diabetes. Public health nutrition, 7(1a), 147-165.

[25] ATMACA, A. (2012). Diagnostic and follow-up criteria of diabetes mellitus. Journal of Experimental and Clinical Medicine, **29(1s)**, 2-6.

[26] Armstrong, R. D., Sinha, P. (1974). Application of quasi-integer programming to the solution of menu planning problems with variable portion size. Management Science, **21(4),** 474-482.

[27] Alphan, E.T. (2016). Nutritional Therapy in Diseases. Ankara, Hatiboğlu Publishing House.

[28] Garille, S. G., Gass, S. I. (2001). Stigler's diet problem revisited. Operations Research, **49(1),** 1-13.

[29] Lancaster, L. M. (1992). The history of the application of mathematical programming to menu planning. European Journal of Operational Research, **57(3),** 339-347.

[30] Satman, I., Yilmaz, T., Sengul, A., Salman, S., Salman, F., Uygur, S., King, H. (2002). Population-based study of diabetes and risk characteristics in Turkey: results of the turkish diabetes epidemiology study (TURDEP). Diabetes care, **25(9),** 1551-1556.

[31] Satman, I., Omer, B., Tutuncu, Y., Kalaca, S., Gedik, S. (2011). Diabetes epidemic in Turkey: results of the second population-based survey of diabetes and risk characteristics in Turkey (TURDEP-II).

[32] American Diabetes Association. (1) Classification and diagnosis of diabetes. Diabetes Care. 2015 Jan;38 Suppl:S8-S16.

[33] American Diabetes Association.(2)(2015). Standards of medical care in diabetes—2015 abridged for primary care providers. Clinical diabetes: a publication of the American Diabetes Association, **33(2),** 97.

[34] Joslin, E. P., Kahn, C. R. (Eds.). (2005). Joslin's Diabetes Mellitus: Edited by C. Ronald Kahn.[et Al.]. Lippincott Williams & Wilkins.

[35] Bilious, R. and Donelly R. (2013). Diabetes Handbook. Istanbul Medical Bookstore.

[36] Corsi, D. J., Subramanian, S. V., Chow, C. K., McKee, M., Chifamba, J., Dagenais, G., Yusuf, S. (2013). Prospective Urban Rural Epidemiology (PURE) study: baseline characteristics of the household sample and comparative analyses with national data in 17 countries. American heart journal, **166(4),** 636-646.

[37] Sacks, F. M., Svetkey, L. P., Vollmer, W. M., Appel, L. J., Bray, G. A., Harsha, D., Cutler, J. A. (2001). Effects on blood pressure of reduced dietary

sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. New England journal of medicine, **344(1),** 3-10.

[38] Marrero, A., Segredo, E., Leon, C. (2019, July). On the automatic planning of healthy and balanced menus. In Proceedings of the Genetic and Evolutionary Computation Conference Companion (pp. 71-72).

[39] Steyn, N. P., Mann, J., Bennett, P. H., Temple, N., Zimmet, P., Tuomilehto, J., Louheranta, A. (2004). Diet, nutrition and the prevention of type 2 diabetes. Public health nutrition, 7(1a), 147-165.Dinneen, S., Gerich, J., Rizza, R. (1992). Carbohydrate metabolism in non-insulin-dependent diabetes mellitus. New England Journal of Medicine, **327(10)**, 707-713.

[40] Armstrong, R. D., Sinha, P. (1974). Application of quasi-integer programming to the solution of menu planning problems with variable portion size. Management Science, **21(4),** 474-482.

[41] Nutrition Subcommittee of the Diabetes Care Advisory Committee of Diabetes UK. (2003). The implementation of nutritional advice for people with diabetes. Diabetic Medicine, **20(10),** 786-807.

[42] Marrero, A., Segredo, E., Leon, C. (2019, July). On the automatic planning of healthy and balanced menus. In Proceedings of the Genetic and Evolutionary Computation Conference Companion (pp. 71-72).

[43] Norris, S. L., Engelgau, M. M., Narayan, K. V. (2001). Effectiveness of self-management training in type 2 diabetes: a systematic review of randomized controlled trials. Diabetes care, **24(3)**, 561-587.

[44] Kavak, H. 2006. The relationship between type II diabetes mellitus and nutritional habits. Master Thesis (unpublished), Atatürk University, Erzurum.Oral, H. (1999). Menu planning through multiobjective programming: An application in the Turkish Army (Doctoral dissertation, Yeditepe Üniversitesi).

[45] Diabetes Compass Final Press Release, April 2021, Denmark.

[46] U.S. Department of Agriculture, Agricultural Research Service, 2018. USDA Food and Nutrient Database for Dietary Studies 2017-2018.

[47] Aygüneş, H., Binay, S., Çetin, A., & Oral, H. (2001). Operations Research Textbook. Ankara: Turkish Military Academy Publishing House.

[48] Balintfy, J. L. (1964). Menu planning by computer. Communications of the ACM, **7(4)**, 255-259.

[49] Sklan, D., Dariel, I. (1993). Diet planning for humans using mixed-integer linear programming. British Journal of Nutrition, **70(1),** 27-35.

APPENDIX A

MODEL TESTING

Set

i 'yiyecek indeksi' /1*3829/

j 'ogun indeksi' /1*5 /

k 'gun indeksi' /1*28/

l 'yanci indeksi' /3830*4078/

Parameter

c(i) "food carbohydrate"

cp(l) "side food carbs"

f(i) "food fiber"

fp(i) "side food fiber"

fr(i) "sugar"

frp(l) "side food sugar"

ct(i) "food cholesterol"

ctp(l) "side food cholesterol"

Esy(i) "energy of saturated fat for meals"

Esyp(l) "saturated fat energy for yancilar"

Ep(i) "protein energy"

Epp(l) "protein energy burners"

S(i) "food sodium"

Sp(l) "side food sodium"

a(i) "vitamin a of food"

ap(l) "side food vitamin a"

V(i) "vitamin c of food"

Vp(l) "side food vitamin c"

cost(i) "price of meals"

cost(l) "side food price"

variables objective;

binary variables x(i,j,k), y(l,j,k);

equations

obj,

const1(k),

const2(k),

const3(k),

cons5(k),

cons6,

cons21,

cons27(k),

cons7(k),

cons8(k),

cons9(k),

cons10(k),

```
cons11(k),

cons11p(k),

cons12(k),

cons12p(k),

cons13(k),

cons13p(k),

cons14(k),

cons14p(k),

cons15(k),

cons15p(k),

cons16(i),

cons17,

cons18,

cons19,

cons20(k);

obj..            objective=e=(sum((i,j,k), x(i,j,k)*c(i))+ sum ((l,j,k), y(l,j,k)*cp(l)));

const1(k)..      sum ((i,j), x(i,j,k)*c(i))+ sum ((l,j), y(l,j,k)*cp(l))=g=165;

const2(k)..      sum ((i,j), x(i,j,k)*f(i))+ sum ((l,j), y(l,j,k)*fp(l))=g=14;

const3(k)..      sum ((i,j), x(i,j,k)*fr(i))+ sum ((l,j), y(l,j,k)*frp(l))=l=25;

cons5(k)..       sum ((i,j), x(i,j,k)*Esy(i))+ sum ((l,j), y(l,j,k)* Esyp(l))=l=( sum
((i,j), x(i,j,k)*en(i))+ sum ((l,j), y(l,j,k)*enp(l)))*0.07;

cons6..          sum ((i,j,k), x(i,j,k)*cost(i))+ sum ((l,j,k), y(l,j,k)*costt(l))=l=200;

cons21..         sum ((i,j,k), x(i,j,k)*cost(i))+ sum ((l,j,k), y(l,j,k)*costt(l))=g=50;

cons27(k)..      sum ((i,j), x(i,j,k)*ct(i))+ sum ((l,j), y(l,j,k)*ctp(l))=l=200;
```

```
cons7(k)..        sum ((i,j), x(i,j,k)*Ep(i))+ sum ((l,j), y(l,j,k)* Epp(l))=l=( sum
((i,j), x(i,j,k)*en(i))+ sum ((l,j), y(l,j,k)*enp(l)))*0.15;
cons8(k)..      sum ((i,j), x(i,j,k)*S(i))+ sum ((l,j), y(l,j,k)* Sp(l))=l=2300;
cons9(k)..      sum ((i,j), x(i,j,k)*a(i))+ sum ((l,j), y(l,j,k)* ap(l))=g=900;
cons10(k)..     sum ((i,j), x(i,j,k)*V(i))+ sum ((l,j), y(l,j,k)* Vp(l))=g=90;
cons11(k)..     sum (i $(ord(i) le 460), x(i,'1',k))=g=1;
cons11p(k)..    sum (i $(ord(i) ge 461), x(i,'1',k))=e=0;
cons12(k)..     sum (i $((ord(i) ge 461) and (ord(i) le 1287)), x(i,'2',k))=g=1;
cons12p(k)..    sum (i $((ord(i) le 460) or (ord(i) ge 1288)), x(i,'2',k))=e=0;
cons13(k)..     sum (i $((ord(i) ge 1287) and (ord(i) le 3829)), x(i,'3',k))=g=1;
cons13p(k)..    sum (i $((ord(i) le 1286) or (ord(i) ge 2830)), x(i,'3',k))=e=0;
cons14(k)..     sum (i $((ord(i) ge 461) and (ord(i) le 1287)), x(i,'4',k))=g=1;
cons14p(k)..    sum (i $((ord(i) le 460) or (ord(i) ge 1288)), x(i,'4',k))=e=0;
cons15(k)..     sum (i $((ord(i) ge 1287) and (ord(i) le 3829)), x(i,'5',k))=g=1;
cons15p(k)..    sum (i $((ord(i) le 1286) or (ord(i) ge 2830)), x(i,'5',k))=e=0;
cons16(i)..     sum (k, x(i,'3',k))+sum(k,x(i,'5',k))=l=1;
cons17..        sum ((l,k), y(l,'3',k))+sum ((l,k), y(l,'5',k))=l=1;
cons18..        sum ((l,k), y(l,'1',k))+sum((l,k), y(l,'2',k))+sum((l,k), y(l,'4',k))=e=0;
cons19..        sum (k, x('425','1',k))=g=20;
cons20(k)..     sum ((i,j), x(i,j,k)*en(i))+ sum ((l,j), y(l,j,k)*enp(l))=g=1200;
model Diet /ALL/;
option optcr=0;
option reslim =10000000;
option iterlim=10000000;
option rmip = cplex;
SOLVE Diet using mip minimizing objective;
```

```
Display x.l , x.m , y.l, y.m;

execute_unload "DietMenu.gdx" x.L, y.L

execute 'gdxxrw.exe  DietMenu.gdx o=DietMenu.xls var=x.L rng=X!'

execute 'gdxxrw.exe  DietMenu.gdx o=DietMenu.xls var=h.L rng=Y!'
```

CURRICULUM VITAE

1.1 Personal Information

Name and Surname: Esra CEYLAN

1.2 Education

	Graduate School	Year
Master:	Gaziantep University Industrial Engineering Operation Research	2021
Bachelor:	Gaziantep University Industrial Engineering	2019

1.3. Publication

International Conferences

Daily Diet Program Planning with Mixed Integer Programming. International Materials and Engineering Technologies (TICMET) 2020 Conference. Gaziantep Turkey