Meal Planning for Alzheimer's Disease Using an Ontology-Assisted Multiple Criteria Decision-Making Approach

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ABSTRACT

As healthy diets and nutrition are crucial for people with Alzheimer's disease (AD), caregivers of patients with AD need to provide a balanced diet with the correct nutrients to boost the health and well-being of patients. However, this is challenging as they are likely to suffer from aging-related problems (such as teeth or gum problems) that make eating more uncomfortable; the planners, who are usually patients' family members, generally face high pressure, a busy schedule, and little experience. To help unprofessional caregivers of AD plan meals with the right nutrition and flavors, in this paper, the authors propose a meal planning mechanism that uses a multiple criteria decision-making approach to integrate various factors that affect a caregiver's choice of meals for AD patients. Ontology-based knowledge has been used to model personal preferences and characteristics and customize general diet recommendations. Case studies have demonstrated the feasibility and usability of the proposed approach.

KEYWORDS

Alzheimer's Disease, Meal Planning, Multi-Criteria Decision Making, Optimization

INTRODUCTION

The goal of this research is to use artificial intelligence technologies to provide automatic meal plans that benefit the health of people with Alzheimer's disease (AD). AD is the most common form of dementia. It results in progressive changes to the brain, cognitive function, and eventually to everyday activities (Raskin et al., 2015). It starts gradually with early signs including patchy memory loss and subtle changes in behavior. The disease is progressively proceeding; the patient may need aid in all aspects of personal care including their daily diet. AD is complex, and it is unlikely that any one drug or other intervention will successfully treat it. Alternative treatments have been applied to

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improve the patient's brain and general health. One of these efforts includes providing AD patients with proper food and nutrition. Diet has a long time effect on AD, but it is not noticeable in a short time. For AD patients, poor nutrition can significantly raise behavioral symptoms and cause weight loss (Pivi et al., 2012). Healthy meal planning is important to maintain a healthy lifestyle, especially for AD patients with other diet-related diseases such as heart disease, diabetes, obesity, and high blood pressure. Besides providing healthy and nourishing meal options, planning meals can help caregivers of AD save time in meal preparation and take away the stress of figuring out meals daily.

Nowadays, there are many online resources about healthy eating. For example, many websites such as the Alzheimer's Association (*Adopt a Healthy Diet*), the National Institute on Aging (*Healthy Meal Planning: Tips for Older Adults*), and the Mayo Clinic (Roth, 2018; Staff, 2019) has valuable knowledge on diet and AD. Recently, mobile applications have been introduced such as Inc. and MyFoodDiaryfood databases and search engines that track and calculate nutrition and calories to assist with meal planning. Although these information sources and tools are available, meal planning for AD users is still challenging for several reasons. First, with the overwhelming amount of online information, it is difficult for a busy caregiver to decide exactly what is best for the patient he or she is taking care of. Moreover, it is not easy for an unprofessional caregiver to remember all the health guidelines and constraints, and then apply them in their daily care routine. Secondly, the meal plans and recommendations provided by existing applications tend to be generic, and do not consider a specific patient's preferences, multiple health conditions, culture, and traditions. In addition, they do not consider a caregiver's time limits to prepare the meal and economic status to afford the food items. Most importantly, there is no automated meal planner specifically targeting the population of AD. General meal planning applications could not be directly applied to AD users as their planning is mainly based on meal nutrition regulations. Based on recent research on AD diet (Liu et al., 2021), appropriate meals for AD patients should focus on food ingredients. For example, instead of recommending a certain amount of protein and fiber in a meal, an AD diet should emphasize the sources of protein and fiber, for example, whether the protein is from beef or fish, the fiber from green vegetables or supplements. Currently, this issue is not effectively considered and addressed by existing meal planning systems.

To address the problems of existing work and assist AD caregivers to plan meals for their patients, the authors propose an effective meal-planning approach that specifically targets AD patients' dietary needs and considers the various situations and preferences of each family and individual. The authors' meal planning system emphasizes meal ingredients, which is an important consideration for an AD diet. There is no one-size-fits-all diet. One of the authors' goals is to personalize each meal and entree with users' AD conditions while respecting their dietary restrictions, preferences, and concerns. These details will motivate patients to follow their meal plan and adhere to it. Specifically, the authors propose an ontology-assisted multiple criteria decision making (MCDM)-based meal planner. The system utilizes a comprehensive ontology-based knowledge base on food, nutrition, and clinical healthy guidelines for common health issues. The graph model of the ontology captures the AD patient and the caregiver's detailed characteristics, such as their health concerns, food flavor preferences, financial situation, as well as their cultural and traditional background. Knowledge about food, nutrition, and healthy diet guidelines are also defined using ontology and ontology-based rules. Personalization is realized by integrating a user's unique biosocial profile into the system's decision-making process. In addition, MCDM allows meal options to be ranked based on users' preferences.

The contribution of the proposed work is summarized as follows:

1. To the best of the authors' knowledge, this is the first automatic meal planning system tailored to AD patients and their caregivers.
2. In addition to planning a healthy diet for AD patients' brains and general health, other health concerns and diet preferences/constraints are well addressed.
3. Based on an efficient multi-criterion ranking approach, the proposed approach is fast and efficient.

BACKGROUND ON RESEARCH OF DIET IN AD

Research on Diet in AD

Many works have been performed to study dietary factors that affect the risk of AD. In their research (van den Brink et al., 2019), the authors found that higher adherence to the Mediterranean Diet, Dietary Approaches to Stop Hypertension (DASH), or the Mediterranean-DASH Diet Intervention for Neurodegenerative Delay (MIND) can slow down cognitive decline and lower the risk of AD. Among these diets, the MIND diet shows the strongest support. Yusufov et al. (2017) studied how diet and physical activity affected AD incidence and they found strong associations between diet and AD incidence (Ahn et al., 2022; Yusufov et al., 2017). Their research found that combining high-intensity physical activity and the MIND diet were associated with better cognitive health than high-intensity physical activity alone. Barnard et al. (2014) summarized several diet guidelines for a healthy diet for AD. These guidelines are consistent with the MIND diet. They include rules such as minimizing the intake of saturated fats and trans-fat and increasing the use of vegetables, legumes, fruits, and whole grains. In summary, more and more research has found that healthy eating impacts AD development.

AI Techniques for Meal Planning

Automatic meal planning using advanced Artificial Intelligence (AI) techniques has been studied to help users design good diet plans and to make cooking easy. Chávez-Bosquez et al. (2014) propose a hybrid optimization approach for meal planning. This approach integrates mathematical programming as the first module and belief merging as the second module to combine the nutrition guidelines with the user's food desires. Gaál et al. (2007) proposed a menu generator that uses genetic algorithms to prepare weekly menus for users. In the proposed algorithm, the meal-planning problem is split into well-defined sub-problems, and a multi-level structure is employed to solve the problem. Further, Huynh and Hoang (2022) propose an AI-based meal planning approach by estimating the energy expenditure of a user. The proposed approach first estimates a user's energy expenditure using a neural network. Then it makes meal plans based on the energy, using a genetic algorithm.

Meal planning for patients with different health problems is also studied. Zadeh et al. (2019a, 2019b) proposed a meal planning system for type II diabetes patients. This system uses a muti-criteria decision-making approach, analytic hierarchy process (AHP), and an optimization technique based on particle swarm optimization (PSO) to make meal planning. Fox and Bui (2015) proposed an AI-based meal planning system, MARY, for cancer patients. MARY is implemented by collecting rules and applying those rules to the meals.

There are also studies on diet planning for elderly people. For example, the NutElCare system employs semantic web technology to apply semantic reasoning over semantic-based facts (Espín et al., 2016). Using this strategy, diet recommendations can be generated for elderly people. Li et al. (2020) proposed a personalized voice-based diet assistant for caregivers of AD. This system is based on a comprehensive knowledge base including AD diet-related knowledge represented as a knowledge graph. Then semantics-based knowledge graph search and reasoning engine are applied to retrieve useful information to communicate with caregivers of AD. ADDietCoach is another diet system for recommending and commenting on AD users' diets. It also uses the semantic web and logic to provide an expert system. However, all these systems, including NutElCare, ADDietCoach, and the voice assistant, only provide diet recommendations, they do not provide detailed multi-day meal plans for users.

MIND Diet

The authors' proposed approach follows MIND diet guidelines to plan meals for AD patients. MIND stands for the Mediterranean-DASH Intervention for Neurodegenerative Delay. It is a hybrid of the Mediterranean and Dietary Approaches to Stop Hypertension (DASH) diet. Many recent studies show that the MIND diet's slow cognitive decline and AD and Related Dementia (ADRD) with aging (Hyman et al., 2012; Monica Moore et al., 2021; Morris et al., 2015a, 2015b). Research also shows that a MIND diet can lower blood pressure and reduce the risk of heart disease, diabetes, and several other diseases (Golzarand et al., 2022). The MIND diet provides natural plant-based foods while limiting red meat, saturated fat, and sweets. The diet also recommends food portions, but different from other diets, it does not focus on weight loss. The MIND diet includes 15 food groups, among them, 10 groups are considered healthy foods, and 5 groups are considered unhealthy. Healthy foods include green leafy vegetables, all other vegetables, berries, nuts, olive oil, whole grains, fish/seafood, beans, poultry, and wine. Foods to avoid or limit include butter, cheese, red meat, fried foods, pastries, and sweets. The research found that healthy food groups are rich in fiber and contain nutrients, such as Vitamin E, Folate, and Omega-3 fatty acids, which can boost brain health.

Aim of the Study

There is currently no meal planner developed to assist AD patients. The aim of this study is to devise an automatic food planner for AD patients based on the MIND diet. In addition to the MIND diet, this meal planner should consider the users' other health concerns as well as preferences.

METHODOLOGY

This section presents the detailed steps of implementing the meal planning system for AD patients and their caregivers. As a first step, the authors model knowledge needed to make the plans. The knowledge includes information about food, nutrition, user's conditions, and diet guidelines for AD and other health concerns. After the background knowledge has been defined in a machine-understandable format, the authors use them to create personalized plans. The second step is to convert diet recommendations into a machine-executable semantic logic format. The recommendations can then be applied to potential meal options. In the end, the most suitable foods are selected and suggested using a multi-criteria decision-making process based on various user preferences and constraints.

Knowledge Modeling

The system must understand foods and their nutritional information to create a healthy meal plan. The authors use ontology to model this information because it is reusable and makes using existing ontologies easier. In addition, its extensibility allows knowledge to grow and enables human and machine understanding. Although many existing food and nutrition ontologies exist, they cannot be used directly for the proposed system as they do not follow the MIND diet food-group definition. For of this reason, the authors defined a new food and nutrition ontology specifically for MIND diet purposes by re-using and re-organizing existing ontologies as listed in Table 1.

Figure 1 shows part of the ontology the authors defined for their planning system. The major property of this planning system, which distinguishes it from other planning systems, is that it emphasizes food ingredients. Two meals with equal values on major nutrition, but different ingredients may have different impacts on AD users' health. The authors classified and grouped food ingredients based on the MIND diet recommendations. As shown in

Table 1. Existing food ontologies that we reused in our system

	Type of Food	Include Nutrition?	Number of Classes	Number of Properties (object/data)	Number of Individuals	Technology
FoodWiki (Çelik, 2015)	Packaged Food	Yes	62	17/12	1530	OWL, RDF
FoodOn (Dooley et al., 2018)	All kind of Food	Yes	NA	117	9600	OWL-DL
PIPS Food Ontology (Cantais et al., 2005)	All kind of Food	Yes	13	NA	NA	OWL-DL
AGROVOC(Caracciolo et al., 2012)	All kind of Food	Yes	40600	NA	960000	RDF/XML
ISO-FOOD (Eftimov et al., 2019)	All kind of Food	No	1323	155	126	OWL

Figure 1. Part of the food and nutrition ontology

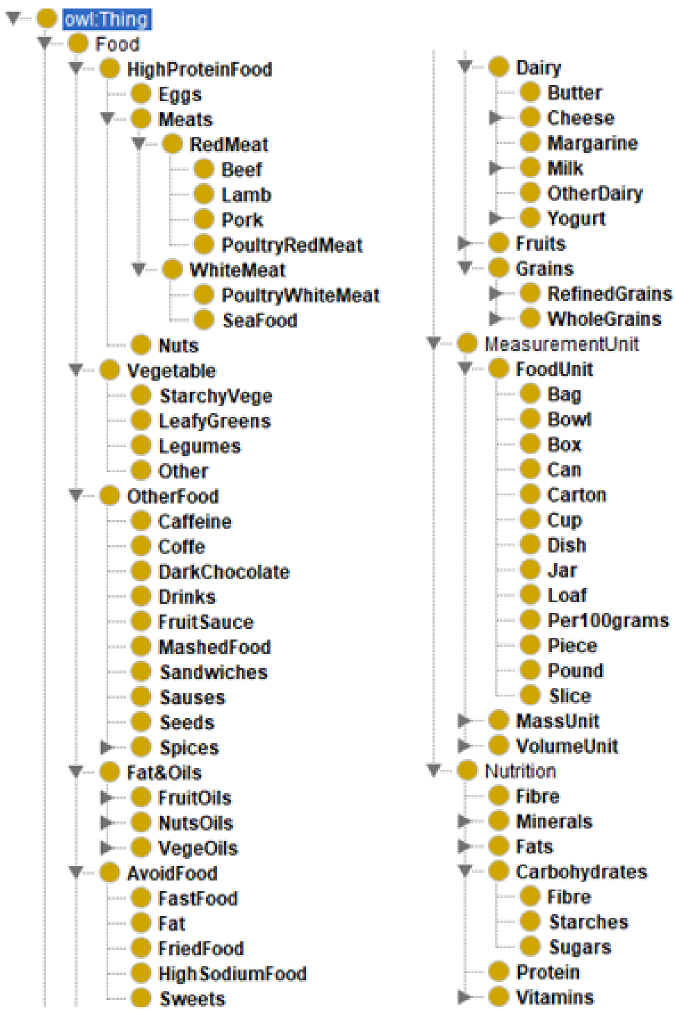

Figure 1, meat has been classified as red meat and white meat; while vegetables are classified as starchy vegetables, leafy greens, legumes, and other vegetables. Based on their food ontology, the authors instantiated it with clustered food items from the USDA's FoodData Central (https://fdc.nal.usda.gov/). With this ontology defined, one can easily follow the MIND diet recommendations. For example, the MIND diet suggests that red meat should be consumed less than four times a week. To follow this recommendation, one should find all red meats in the meals using the ontology, and limit their portions in a weekly plan.

To make a personalized plan, one also needs to know the users, which may include AD patients and their caregivers. Again, this is realized through ontology modeling. Specifically, the authors reused the ADOnto ontology (Li et al., 2021) that was designed for AD care in general, and then picked the parts that were related to diet and eating. They chose concepts and relationships that may affect an AD patient's diet decision from an AD patient's capability profile, health profile, and preference profile. For example, the authors needed to understand if a patient is able to eat independently. They also chose some concepts from the caregiver's profile that were related to meal planning.

Diet Rule Application

The MIND diet encourages 10 foods to eat and 5 foods to avoid. The authors converted these guidelines into semantic rules that could be applied to the meal planning process. Through reasoning, they could identify whether or not a meal was appropriate. For example, MIND suggests eating another vegetable in addition to green leafy vegetables at least once a day. This can be defined as an SWRL rule:

```
Meal(?meal) ^
(hasVegetables >=2 Vegtables) (?meal) ^
(hasVegetables >= 1 LeafyVegetables) (?meal) ->
passVegiRule (?meal, True)
```

Besides MIND diet recommendations, other diet-related rules, such as health-related rules (e.g., diabetes), allergy-related rules, and religious-related rules were generated using a similar approach. For example, if a specific user had hypertension and does not eat beef because of religious restrictions, the previous SWRL rule would be updated to the following:

```
Meal(?meal) ^
User(?user) ^
Hindus(?religion) ^
hasMeal(?user,?meal) ^
hasReligion(?user,?religion) ^
(hasVegetables >=2 Vegetables) (?meal) ^
(hasVegetables >= 1 LeafyVegetables) (?meal) ^
(hasMeat < 1 Beef) (?meal) ^
hasSodiumLimit(?user,?userSodiumLimit) ^
hasTotalSodium(?meal,?mealTotalSodium) ^
swrlb:lessThan(?mealTotalSodium, ?userSodiumLimit) ->
passMealRestrictions (?meal, True)
```

Based on the MIND diet rules and other diet-related rules, the authors could identify whether a meal item followed these rules. For example, suppose a meal has ingredients of one serving of spinach and one serving of zucchini and tomato. In this case, the reasoning system will determine that this meal follows the MIND rule about vegetables. Based on the ontology logic, spinach is a green leafy vegetable, and zucchini and tomato are vegetables. Therefore, this follows the MIND recommendation regarding vegetables.

Meal Planning Based on Ingredient

The authors designed a simple yet effective approach to make a one-week meal plan. It can also be customized for any period of time, such as three days, 10 days, or a month. The planning algorithm starts with creating a random diet table that is filled with the major ingredient groups defined in the ontology that follow the MIND diet for one week. For example, Table 2 is a such a diet table. It shows the main ingredients of each meal and is created to simplify and summarize all MIND diet rules for one week.

This initially randomized simple table provides an effective way to make planning organized and follow most of the guidelines. For example, the MIND diet encourages eating at least three servings

Table 2. Ingredient type in diet table (Meal-table rules)

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Breakfast	Grain, Nuts	Grain, Berry	Grain, Nuts	Grain, Nuts	Grain, Berry	Grain, Nuts	Grain, Nuts
Lunch	Grain, Vegetable	Grain, Vegetable	Grain, Vegetable	Grain, Vegetable	Grain, Vegetable	Grain, Vegetable	Grain, Vegetable
Dinner	Grain, Beans	Grain, Poultry	Grain, Beans	Grain, Seafoods	Grain, Beans	Grain, Poultry	Grain, Beans

of grains a day. Then we put one serving of grains in each meal of a day. It incorporates grains into all three meals a day to achieve this goal. The MIND diet also recommends eating two poultry meals a week; thus the table is scheduled to ensure that one does not miss poultry twice a week. After initializing with ingredient groups in the ontology, the table can then be used as a matching pattern to choose meals fitting for the pattern.

Meal Ranking

Only meals that match the MIND diet patterns defined in the one-week table are selected for further processing. This processing will include user's preferences into consideration. The planning algorithm uses the technique for order of preference by similarity to the ideal solution (TOPSIS) techniques. TOPSIS is one of the multi-criteria decision-making methods. It involves mathematical tools and psychological approaches (Panda & Jagadev, 2018). This technique compares a set of alternatives based on a pre-specified criterion. It makes complex decisions by pairwise comparisons of all the critical factors based on priorities. To find the best alternative, TOPSIS looks for the one nearest to the positive ideal solution and farthest from the negative ideal solution (Olson, 2004). One of the advantages of TOPSIS is that it specifies the type of optimization for each criterion. The benefit criteria are maximized, and the cost criteria are minimized in the positive ideal solution. Other advantages of TOPSIS include simplicity, responsiveness to many options and criteria, and ease of quantifying the qualitative criteria. TOPSIS is a rational method that provides very efficient computations in a simple mathematical form. Therefore, the best alternative can be identified quickly (Panda & Jagadev, 2018).

The planning system considers various users' preferences, such as cuisine flavor, favorite ingredients, cost, cooking time, etc. In TOPSIS, all the input particles will be taken at a time as alternatives, and they will be given a score based on the criteria called the "decision matrix." Using the TOPSIS method, one can find the best alternative from the decision matrix. One issue in TOPSIS is the identification of the weight of each criterion. The authors proposed to use AHP (analytic hierarchy process) weight matrix to solve this problem.

The AHP process consists of the following two main steps:

1. Determine the user's preference criteria using Saaty's fundamental scale (Saaty, 2001).

Use the importance score to create a pairwise comparison matrix. Square matrix N×N, $A = \left\{a_{ij}\right\}$. In matrix A, N represents the number of criteria, and each a_{ij} indicates the importance of i^{th} criterion as compared to j^{th} criterion, as determined by the user's responses. A value below the original diameter exhibits an inverse correlation with a value above it, i.e., $a_{ij} = \frac{1}{a_{ji}}\left(\forall i \neq j\right)$, and the main diameter is one, i.e., $a_{ii} = 1$.

2. Determine the weights of the preference criteria using the following math operations.

The $1 \times N$ normalized eigenvector, also known as the weight vector, is computed via comparison matrixes. Using the weight vector, one can see how relative the weights of the compared alternatives are: $w_i = \frac{\sum_{i=1}^{N} \bar{a}_{ij}}{N}$, w_i is weight of i^{th} criterion and $\bar{a}_{ij}$ is the normalized j^{th} element of i^{th} row of matrix A.

By using AHP methods, the authors were able to obtain the weights of each of the criteria. The next step was to rank the alternatives using TOPSIS. The following are the steps involved in TOPSIS:

- Create a normalized decision matrix to evaluate alternatives.
- Analyze the ideal solution from both a positive and negative perspective.
- Utilize the weight matrix to calculate the separation measures.
- Calculate the distance between the solution and the ideal solution.
- Sort the preferences according to their score.

Applying the planning algorithm, the optimal meals can be identified from a large number of candidate meals.

EVALUATION

The authors created their test set with many online recipes that could be potential meal options. Recipes were collected by crawlers developed with the Scrapy framework, a free and open-source web-crawling framework written in Python for crawling and parsing. The primary source for extracting recipes was the Food.com website, from which they built a data set that contains 176,206 meals. Each meal recipe had nutritional information. The data set was preprocessed and prepared for use. Some scale changes were made based on the USDA food database. Then, user information, such as biometric information, health issues, and preferences were collected. The planning algorithm considered the user's AD health and other health issues, culture or religious restrictions, food constraints, budget limitations, and time limitations. It also viewed personal preferences, including flavor, popularity, rating, and serving size preference.

Use Case Evaluation

First, the authors employed a use case study to evaluate the validity and appropriateness of the proposed meal-planning mechanism. Use case evaluation is a usability evaluation based on use cases. In this evaluation, they created hypothetical users and used the system from the users' perspective to see if the system provided the intended services as expected. Assume there are two AD patients whose caregivers use the proposed system to plan meals for a week. Use case 1, a 70-year-old male user, has early-stage AD, he also has type II diabetes, and he is allergic to peanuts. His BMI value is 24.5. His caregiver cares about the cost of the meals, preferring meals that are more economical. In addition, the time needed to prepare the food is important to consider, as she is very busy. Case 1 prefers food from his favorite cuisine lists, and he likes Mexican, Asian, and Vegetarian cuisines. His caregiver sometimes looks at the rating number of meals to choose meals. Based on Case 1's health constraints and preferences, the authors' system made the following recommendations shown in Table 3.

Table 3 shows a one-week plan for use Case 1. It can be seen that it complies with the Meal-Table rules presented in Table I. The dark part of the table indicates the type of ingredient used in each recipe. One can see, for instance, that grains are a part of every meal. In this one-week plan, vegetables are served in all lunches. In addition, mandatory personal rules are considered separately. For instance, Case 1 has been restricted as to the amount of carbs he consumes every day because of diabetic restrictions, and all meals containing peanuts have been avoided due to his allergy constraint.

Table 4 provides more information about the user's preferences. As the caregiver is concerned about the cost of meals, one can see the meals planned are low-cost meals, also the cooking times are short to fit the caregiver's busy schedule.

Use Case 2, a 60-year-old female, is another AD patient. She has BMI value of 23.7 and no specific health concern. She permanently avoids pork. She lives with her five other family members. Case 2's caregiver makes food for the whole family including Case 2. Food price and preparation time are less important, and favorite cuisine is of average importance. Her caregiver cares a lot about a meal's online rating. It is also important to know the number of servings so that she can easily scale the

Table 3. One week plan for use case 1

	Breakfast	Lunch	Dinner
Day 1	Mixed Whole-Grain Breakfast (W/ Gluten Free Option)	Fresh Corn Chowder (Raw Food)	Black Bean, Corn, and Tomato Salad
	Grain, Nuts	*Grain, Vegetables*	*Grain, Green-Vegetables, Beans*
Day 2	Cinnamon-Apple Oatmeal	Deluxe Dinner Salad for 2	Thai Chicken Fried Rice with Basil - Kao Pad Krapao
	Grain, Nuts	*Grain, Vegetables, Green-Vegetables, Beans*	*Grain, Seafood, Poultry*
Day 3	Apple, Banana, Oatmeal Treat for One	Vegetarian Apple Stir-Fry	Mexican Omelet
	Grain, Nuts	*Grain, Vegetables*	*Grain, Vegetables, Beans, Red-Meat*
Day 4	Firefighter's Honey Muesli	Brown Rice Veggie Sushi Bowl with Fat Free Spicy Mayo	Garlic and Egg Fried Rice
	Grain, Nuts, Berry	*Grain, Vegetables*	*Grain, Seafoods*
Day 5	Maple Walnut Hot Cereal with Quinoa	Salmon and Noodle Salad	Vegetarian Mexican Stir-Fry
	Grain, Nuts	*Grain, Vegetables, Seafood*	*Grain, Vegetables, Beans*
Day 6	Creamy Berry Oatmeal	The Moroccan Pita Sandwich (ZWT-9)	Hot & Spicy Chicken (Shrimp) Fried Rice
	Grain, Berry	*Grain, Vegetables, Green-Vegetables, Poultry*	*Grain, Vegetables, Poultry*
Day 7	Vanilla Spice Oatmeal	Roasted Garlic Couscous with Tomatoes & Basil	Easy Vegetarian Black Bean Tortilla Soup
	Grain, Nuts	*Grain, Vegetables*	*Grain, Vegetables, Beans*

Table 4. Details of the first day meals for use case 1

Meal	Ingredient	Price $,$$,$$$	Time Needed to Prepare	Cuisine	Rating	No. Serves	Preference Score
Mixed Whole-Grain Breakfast (W/Gluten Free Option)	buckwheat groats, millet, rolled oats or quinoa, red apple, almonds or favorite nuts, raisins or dates, cinnamon, cardamom, ground flax seeds, milk or yogurt, honey to taste	$	20 min	Vegetarian	5	2	0.95
Fresh Corn Chowder (Raw Food)	corn, tahini, scallions, pumpkin pie spice, dash pepper, red bell pepper, cilantro	$	5 min	Vegetarian	2	5	0.96
Black Bean, Corn, and Tomato Salad	olive oil, black beans, fresh corn kernels, plum tomato, scallion, fresh parsley leaves, cayenne, lettuce leaves	$	25 min	Vegetarian	2	4.7	0.93

ingredients. Case 2 likes Chinese, Indian, and Mediterranean cuisine. Based on Case 2's constraints and preferences, the authors' system made the following plan recommendations as shown in Table 5.

Table 6 provides more information about preferences. For example, case 2 cares more about "Number of serves" and "Rating," so meals that meet these criteria receive a higher score and are selected as menu items.

Manual Verification

After the initial use case study, the authors found that the proposed meal plan was valid and appropriate. They then generated long-term plans for both patients, Case 1 and 2. The authors created meal plans for three months (including 270 meals), and checked manually on all the meals to see if they followed

Table 5. One week plan for use case 2

	Breakfast	Lunch	Dinner
Day 1	Iranian Saffron Rice Pudding (Sholeh Zard) (Dairy Free & Glu	Easy Fried Rice	Chinese Beef and Asparagus with Black Bean Sauce
	Grain, Nuts	Grain, Vegetables	Grain, Beans, Poultry, Red Meat
Day 2	Healthy Maple Walnut Baked Oatmeal	Quinoa Tabouli	Chinese Fish and Lettuce Soup
	Grain, Nuts	Grain, Vegetables, Green-Vegetables	Grain, Green-Vegetables, Sea-foods, Poultry
Day 3	Maple-Walnut Granola	Cashew Chicken	Achingya Thoren (Kerala Style Green Bean Curry)
	Grain, Nuts	Grain, Vegetables, Poultry, Nuts	Grain, Beans
Day 4	Gingerbread Pancakes (Healthy, Whole Wheat, and Low-Fat)	South Indian Cabbage and Carrot	New England Kedgeree
	Grain, Nuts, Berry	Grain, Vegetables	Grain, Green-Vegetables, Sea-foods
Day 5	Healthy Whole Wheat Pumpkin Pie Pancakes	Seven Layer Chinese Chicken Salad	Wok-Seared Sesame Green Beans
	Grain, Vegetables, Nuts	Grain, Vegetables, Green-Vegetables, Poultry, Nuts	Grain, Beans
Day 6	Whole Wheat Pancakes with Blueberry Compote	Healthy Baked Falafel	Gai Lan (Chinese Broccoli) With Oyster Sauce
	Grain, Berry	Grain, Vegetables, Green-Vegetables	Grain, Poultry
Day 7	White Chocolate Apple Muffins	Our Iraqi “timman” – Rice	Short-Cut Vegetable Biryani
	Grain, Vegetables, Nuts	Grain, Vegetables	Grain, Vegetables, Beans, Nuts

Table 6. Meal details of the first day for use case 2

Meal	Ingredient	Price $,$$,$$$	Time Needed to Prepare	Cuisine	Rating	Number Serves	Preference Score
Iranian Saffron Rice Pudding	basmati rice, sugar, canola oil, rose water, saffron, almonds, pistachios, cinnamon	$$	130 min	Mediterranean	4.5	6	0.84
Easy Fried Rice	rice, oleo, onion, celery, garlic, carrots, peas, ginger, eggs, soy sauce, pepper	$	30 min	Chinese	4.7	5	0.99
Chinese Beef and Asparagus with Black Bean Sauce	asparagus, steak, peanut oil, soy sauce, ginger, dry sherry, cornstarch, garlic cloves, black beans, chicken broth	$$	25 min	Chinese	5	5	0.91

all of the applicable rules and constraints. They found all meals followed the MIND rules, health-related diet rules, religious rules, and other mandatory restrictions (Table 7). The health diet rules, such as allergy or disease guidelines, were strictly followed.

Qualitative Evaluation

The National Heart, Lung, and Blood Institute (NHLBI) presents a plan for a MIND diet for one week (A Week With the DASH Eating Plan). Here is a comparison between their suggested ingredients and the authors’ based on the serving size (Table 8). Both plans cover the minimum expected amount

Table 7. Manual verification of two user cases

User	Number of Meals	Health Rule	MIND Rule	Religious and Mandatory Rules
No 1	270	100%	100%	NA
No 2	270	NA	100%	100%

Table 8. Comparison of serving numbers of ingredients in two separate systems

Plan	Grain	Vegetables	Meats, Fish, and Poultry	Nuts, Seeds, and Legumes	Preference Score
Our plan	35	31	11	14.5	5.6
NHLBI plan	41.25	36.5	34	9.25	4.8

of ingredients. However, the difference lies in considering the user's preferences and providing customized suggestions instead of generic meals. Another way to explain the difference is that the NHLBI plan is a general plan, it is not personalized based on the user's preferences.

DISCUSSION

The evaluation results demonstrate the main advantages of the proposed AD meal planning system; it considers not only the nutritional value, but also the ingredients' food groups of a meal. Based on the results obtained in the case study, the diet plans provided by the system are AD-beneficial, and personalized. All MIND Diet rules are applied, and each user's health rules are considered. In the manual verification process, each meal was checked based on all the AD and health-related rules: each required ingredient and nutritional value should not fall below the minimum specified value or exceed the maximum specified value. The authors also observed that this system can make long-term plans. There is, however, a presumption that the situation and conditions are stable and non-dynamic. From quality evaluations, the authors found that compared with the perfectly expert-made plans, their plan may show less rich in major components, but their plan gets higher personal preference scores. Personal condition and preferences are an essential factor that drives users' satisfaction and encourages them to continue to follow the suggested plan.

CONCLUSION

To address the limitations of current meal planning systems and fill the gap in meal planning for AD patients, the authors proposed an AI-enabled meal planning system tailored for an AD diet. The proposed system utilizes ontologies of food, nutrition, and AD user profile as the knowledge foundation to create meal planning. MIND recommendations, in the form of semantic logical rules, are applied to screen meal ingredients. An ingredient-based initial planning is then applied to potential meals that must satisfy the ingredient requirements of the MIND diet. A novel heuristic-based multi-criteria analysis is then employed to rank meals to obtain the optimal meals that not only follow the AD diet guidelines but also meet users' preferences.

The authors have tested the proposed system using a large meal database containing 176,206 meals. Use case-based evaluations have been performed. The case studies show that the meals planned for each case appropriately follow AD guidelines and meeting users' preferences. Five hundred and forty meals were manually checked for two user cases.

This work is ongoing research, and it has limitations. The proposed system was only evaluated by use cases without real user studies. How users like and adhere to the plan is not known. The system cannot handle dynamic situations. For example, for a weekly plan, if a user does not follow the plan on some days, there is currently no remedy options provided for the user. In the future, a prototype system will be developed, and user studies will be conducted. The authors will improve the system based on the feedback collected from the user studies. In addition, they will examine how to accommodate dynamic changes, so that the planning system can automatically adjust itself based on the user's dynamic changes.

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