# Group 3 Final Report
# A Customizable Solution for a Balanced Diet

## Introduction

Single-person households are becoming increasingly popular in Canada. Up from only 7% in 1951, approximately 30% of Canada's entire population now lives in single individual dwellings. A University of Minnesota study finds that leading a busy lifestyle has adverse implications on eating behaviors among young adults, often because they do not have the time or energy to plan nutritious meals (American Journal of Health Behaviour). As an attractive destination for many young professionals and students every year, Toronto is at the forefront of this social issue. For many residents leading a rushed and fast-paced lifestyle, planning a flexible and balanced diet that caters to their tastes is a difficult challenge.

Our project aims to develop an optimization tool for designing a personalized daily meal plan for health-conscious, yet busy, individuals with average cooking ability. Given a user's available ingredients and personal preferences, the tool determines a list of recipes to cook for the day. While the tool guarantees quotas are met across nine different nutrients (i.e. protein, carbs, etc.), it is also highly customizable and considers the user's preferences for nutrition, cooking difficulty, cuisine, and flavour profile.

## Data

The optimization tool is powered by recipe data from the Yummly API and by calorie and nutritional guidelines from the U.S. Office of Disease Prevention and Health Promotion. For customization, users are asked to enter their personal attributes and preferences. The relevant attributes in the recipe data and nutrition guidelines are compiled as tables in CSV format. In the following sections, we will outline the specific data features collected and the important data transformation steps.

<u>Recipes Data</u>

Yummly API allows access to recipes posted on various food websites through a web data request call. In particular, our tool uses the following data attributes in our optimization model:

- Nutritional content: the amount of nutrients (*protein*, *carbohydrates*, …) contained in the recipe
- Preparation and cooking time
- Required ingredients and amounts
- Meal flavour profile on a scale from 0 to 1: *salty*, *sour*, *sweet*, *bitter*, *meaty*, *piquant*
- Cuisine type

<u>Nutrition Data</u>

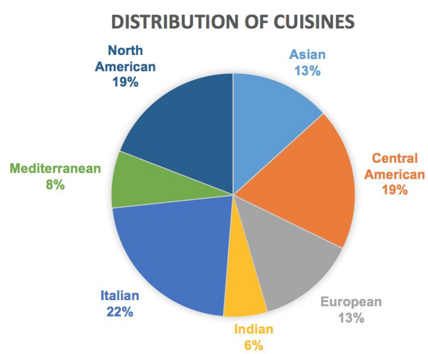
The recommended daily nutrition intake information is taken from the Dietary Guidelines Handbook published by U.S. Office of Disease Prevention and Health Promotion. According to age, sex, and activity level of the individual, recommended daily amounts for the 9 key nutrients are suggested in the handbook.

<u>User Input Data</u>

In addition to providing available ingredient amounts, users will be asked to enter their personal preferences: preferred meal flavours, preferred cuisine types, maximum desired cooking time, and total number of ingredients to work with. Users may also choose to specify relative importance for preferences and set nutrition limits instead of using government recommendations.

<u>Exploratory Analysis & Data Transformation</u>

The code for data fetching and transformation is documented in Appendix A2. The Yummly API was repeatedly called to collect approximately 10,000 recipes of different cuisines. This data was in the JSON format, where the ingredient and nutrition information was stored in multiple nested dictionaries. Data attributes were extracted and saved in CSV format using Python scripts. After deleting recipes that only had a rating of 1 out of 5 or have missing ingredient lists and cooking time, the final list contained 8,118 recipes.



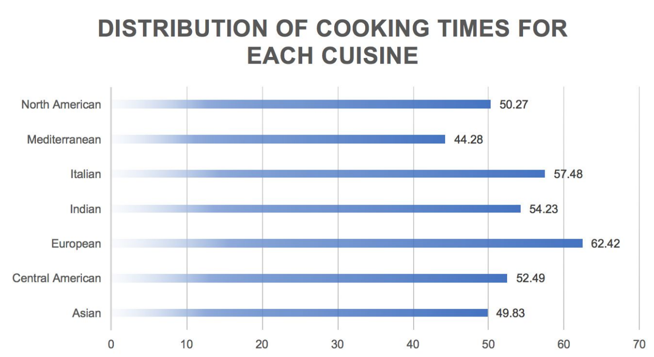




**Fig. 1**. (left): Distribution of cuisines across all 8118 recipes.
**Fig. 2.** (right): Distribution of cooking times for each of the 7 cuisines

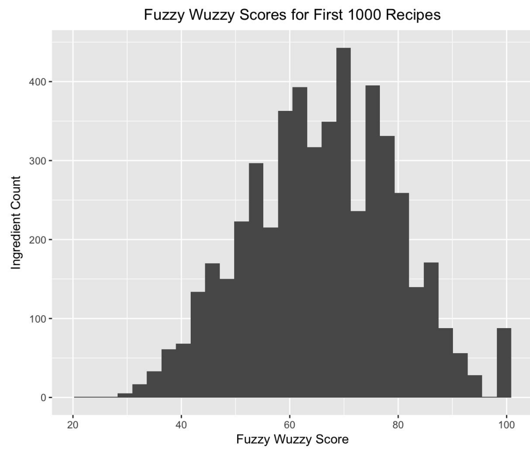
At this stage, there were 33 unevenly distributed cuisine types listed by default which were compressed to 7 broader classes. Some unlabeled recipes were also properly placed into classes based on ethnic ingredient or recipe names (e.g. anything with Teriyaki in the recipe name was labelled as Asian, recipes with Feta were labelled as Mediterranean). In the end, a more condensed and balanced distribution of cuisines across recipes was obtained (Fig. 1).

Fig. 2 presents the distribution of cooking times across the 7 cuisine labels. There are varying degrees of cooking time complexity, ranging from time efficient 2-minute recipes to recipes requiring preparation days in advance. The overall average across all recipes is 53 minutes. The average cooking time is the highest for European meals at 62.42 minutes and the least for Mediterranean meals at 44.28 minutes. This information provides us with some insight into how increasing preference weight for short cooking times can increase the likelihood of prescribing Mediterranean recipes.

In addition to investigating the categories of cuisine and cooking times, analysis was performed on constituent ingredients of each recipe to be used in the optimization problem. In terms of ingredients required for the recipes, the number varied between 2 and 27 ingredients. Average number of ingredients was 5.5. This can be used in the optimization as a benchmark for recipe complexity. Average number of ingredients per recipe also depends on cuisine type; Indian recipes have the highest average at 8.2 ingredients whereas North American recipes had an average of 5.8 ingredients. This gives us an insight that if the user is not a very experienced cook, the model will likely suggest North American recipes.

Initially, it was found that 73,800 ingredients were present, with 11,547 of them being unique. Evidently, there was room to reduce the size of the data provided by consolidating ingredients such as “salt”, “pepper”, and “salt and pepper”. Names of each unique ingredient should be standardized across different recipes. For example, “frozen beans”, “parboiled beans”, “beans, washed and cut” should all be relabelled to “beans”. Doing so would reduce the noise associated with the ingredient names and amounts, as well as the total number of ingredients per recipe.

First, in order to reduce the dimensionality of the ingredient matrix, the team procured a list of ingredients that was 298 items long. It was important that this list be diverse enough that it can accurately covers the 11,547 unique ingredients. Because the ingredient amounts and units for each recipe were presented as one string, a script was written to extract and populate them into an usable data structure. All numbers were removed from the string and taken to be ingredient amounts. The ingredient names were extracted by removing unit words such as "cups", "grams", or "tablespoons".



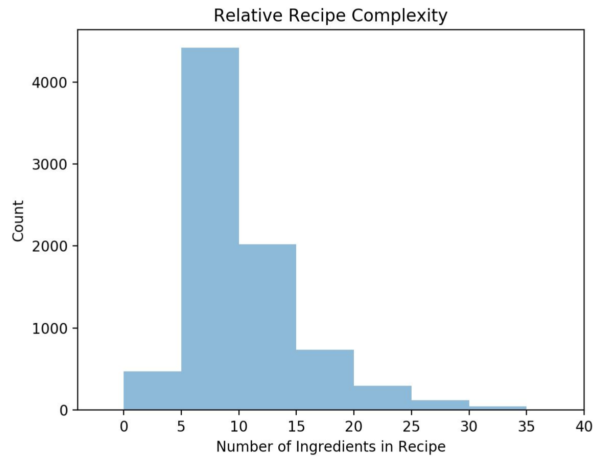




**Fig. 3** (left): Distribution of fuzzy wuzzy similarity score for the first 1000 recipes.
**Fig. 4** (right): Distribution of number of ingredients across 8118 recipes.

Next, the Python package, *fuzzy wuzzy*, was used to calculate a similarity score between each ingredient name and the condensed ingredient list we wanted to map it to. If this similarity passed a certain threshold, it was remapped to the desired list of ingredients. The ingredient strings that did not pass this test were manually changed using find and replace methods. Figure 3 is the distribution of similarity scores for the first 1000 recipes, where more than 95% of ingredient names had a similarity score of 50 and above to one of the ingredients in the condensed list. We chose a threshold of 50% since this leaves a reasonable number of ingredients to relabel. After the cleaning, an additional feature that indicates the number of ingredients in a recipe was added. In our final list, the majority of recipes use 5-10 ingredients according to Figure 4, a range that is realistic and representative of a meal requiring "average culinary skills" for the user.

## Methods

A MATLAB tool has been developed to process user inputs, call the MATLAB-Gurobi solver, and display results (please refer to appendix A1 for implementation details). To determine the optimal set of recipes to cook for the day, a mixed integer linear program is formulated and presented below.

Decision Variables

$r_j$ (binary): recipe $j$ is chosen or not $j \in J$

$b_i$ (continuous): weighted reward value on preference $i$, $i \in I$

$s_g$ (binary): indicator of whether conditions associated with soft constraint are satisfied $g \in G$

Sets

$N = \{protein,\ carbohydrates,\ fibre,\ fat,\ iron,\ vitamin\ C,\ sodium,\ calcium,\ calories\}$

$F = \{salty,\ sour,\ sweet,\ bitter,\ meaty,\ piquant\}$

$C = \{North\ American,\ Asian,\ European,\ Central\ American,\ Mediterranean,\ Italian,\ Indian\}$

$I = \{nutrient_1,\ nutrient_2,\ cooking\ time,\ cuisine,\ flavours,\ number\ ingredients\}$

$G = N \cup F \cup C \cup \{cooking\ time,\ number\ ingredients\}$
$K = \{297\ ingredients\ contained\ in\ the\ recipes\ data\}$
$J = \{8118\ recipes\ in\ the\ recipes\ data\}$

Data Parameters

$M_n$ - amount of nutrient $n$ recommended by health agency (optionally: user specified target amounts)
$N_{nj}$ - amount of nutrient $n$ in recipe $j$, $n \in N$, $j \in J$
$T_j$ - time required to cook recipe $j$, $j \in J$
$I_{kj}$ - amount of ingredient $k$ required for recipe $j$, $k \in K$, $j \in J$
$F_{fj}$ - degree of flavour $f$ in recipe $j$ (on a scale from 0 to 1) $f \in F, j \in J$
$C_{cj}$ - indicator for whether recipe $j$ is representative of cuisine $c$, $j \in J, c \in C$
$K_j$ - number of ingredients used in recipe $j$, $j \in J$

User Input Parameters

$A_k$ - amount of ingredient $k$ available $k \in K$
$W_i$ - weight assigned to preference $i$, $i \in I$
$UF_f$ - indicator for whether flavor $f$ is preferred by the user $f \in F$
$UC_c$ - indicator for whether cuisine $c$ is preferred by the user $c \in C$
$TimeLimit$ - amount of time user prefers to spend on cooking for the whole day
$NumIngredients$ - maximum number of ingredients the user prefers to work with for the day

Objective

Maximize sum of rewards from satisfying preferences: $\max \sum_{i \in I} b_i$

Preference Constraints

1. Prefer excess consumption of nutrients that are beneficial

$$\text{If } (\sum_j N_{nj} r_j \geq M_n) \text{ then } s_n = 1 \text{ else } s_n = 0 \quad \forall n \in \{fibre, iron,\ vitamin\ C, calcium\}$$ [1]

2. Prefer consuming at most 5% more than target consumption, for nutrients that should not consumed in excess

$$\text{If } (\sum_{j \in J} N_{nj} r_j < 1.05 M_n) \text{ then } s_n = 1 \text{ else } s_n = 0 \ \forall n \in \{protein,\ carbs,\ fat,\ sodium,\ calories\}$$

3. Prefer being under user specified time limit

$$\text{If } (\sum_{j \in J} T_j r_j < TimeLimit) \text{ then } s_{cooking\ time} = 1 \text{ else } s_{cooking\ time} = 0$$

4. Reward provided for selecting recipes representative of the user-preferred cuisines

$$\text{If } (\sum_{j \in J} C_{cj} r_j \geq 1) \text{ then } s_c = UC_c \text{ else } s_c = 0 \quad \forall c \in C$$

5. Prefer recipes containing flavours designated as ‘preferred’ (sum of flavour levels greater than 2)

$$\text{If } (\sum_{j \in J} F_{fj} r_j > 2) \text{ then } s_f = UF_f \text{ else } s_f = 0 \quad \forall f \in F$$

[1] Constraint does not apply to the other nutrients (carbohydrates, protein, fat, and sodium) because doing so is not beneficial according to studies by Harvard, National Institute of Health, Delimaris et al., and Leibowitz et al.

6. Prefer if total ingredients used is less than user specified number

$$\text{If } (\sum_{j \in J} K_j r_j \leq NumIngredients) \text{ then } s_{number\ ingredients} = 1 \text{ else } s_{number\ ingredients} = 0$$

<u>Hard Constraints</u>

1. Total amount of ingredient $k$ used must be less than the amount of ingredient available to the user

$$\sum_{j \in J} I_{kj} r_j \leq A_k, \ \forall k \in K$$

2. At least three recipes prescribed for the day's meals

$$\sum_{j \in J} r_j \geq 3$$

3. Total amount of each nutrient consumed greater than 75% of target amount

$$\sum_{j \in J} N_{nj} r_j \geq 0.75 M_n, \ \forall n \in N$$

4. Nutrition intake must be less than twice the target amount

$$\sum_{j \in J} N_{nj} r_j < 2 M_n, \ \forall n \in N$$

5. Constraints to set the weighted reward for each preference $i \in I$, according to the indicator constraints

i) $b_{nutrient_1} = W_{nutrient_1} \frac{1}{4} \sum_n s_n \ \ n \in \{fibre, iron, vitamin\ C, calcium\}$

ii) $b_{nutrient_2} = W_{nutrient_2} \frac{1}{5} \sum_n s_n \ \ n \in \{protein, carbohydrates, fat, sodium, calories\}$

iii) $b_{cooking\ time} = W_{cooking\ time} s_{cooking\ time}$

iv) $b_{cuisine} = \frac{W_{cuisine}}{\sum_{c \in C} UC_c} \sum_{c \in C} s_c$

v) $b_{flavours} = \frac{W_{flavuors}}{\sum_{f \in F} UF_f} \sum_{f \in F} s_f$

vi) $b_{number\ ingredients} = W_{number\ ingredients} s_{number\ ingredients}$

<u>Model Adjustments</u>

After several iterations of testing, adjustments were made to the optimization model to improve the effectiveness of constraints in capturing user preferences and the sensibility of model parameters.

Initially, we believed that the tool should prescribe only three recipes to cook due to the limited time available and that each recipe is supposed to be assigned to a meal in the day. However, we quickly found that a substantial proportion (21%) of recipes are "snack-type" recipes that should not be considered as meals. Furthermore, we found that around 25% of the recipes can be prepared within 15 minutes, thereby increasing the practicality of assigning more than three recipes for a given day. Hence, this constraint was changed to "at least 3 recipes prescribed".

We also added a constraint to disincentivize consuming certain nutrients in excess (i.e., protein, fat, sodium) because studies have shown that overconsumption of these nutrient may pose health complications and is generally not beneficial for the body (Harvard, National Institute of Health, Delimaris, and Leibowitz). The goal of the meal optimizer is to match the preferred thresholds closely, instead of attempting to exceed them. In addition, the option for users to specify target limits on the nutrients (instead of using the health agency guidelines) enables flexibility in consumption: a bodybuilder can, for instance, still receive recipes with higher than normal protein content.

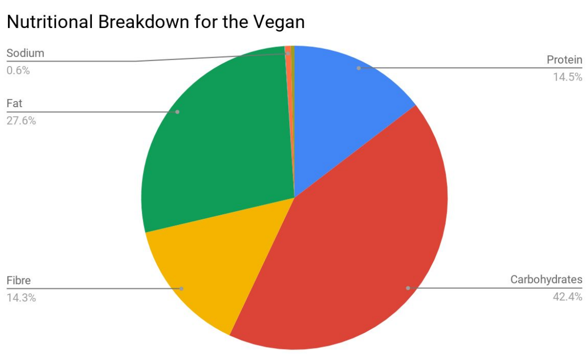
Several coefficients in the soft constraints were adjusted to improve their effectiveness. For example, the hard constraint for minimal consumption of nutrients was initially 50% instead of 75%, which produced recipe lists containing too few main dishes and therefore unrepresentative of a daily meal plan. Additionally, the threshold for satisfying a flavour preference was initially set to 0.5 instead of 2, which was found to be too low as certain recipes that generally do not characterize a flavour are still given a non-zero value on the scale of 0 to 1 (i.e. a tofu dish being rated as 0.75 out of 1 for 'meaty').

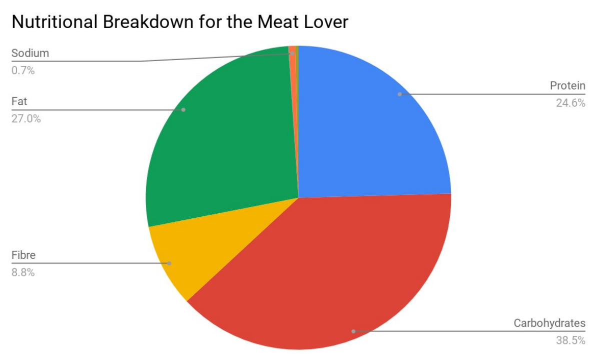
## Results and Discussion

Several pairwise case studies are examined to validate model performance and effectiveness across various user profiles. The objective of each pairwise case study is to assess the sensitivity of the model to different parameters by comparing individuals who differ in one or two of the following areas at a time: dietary preferences, age, activity level, lifestyle, ethnicity, and gender. Only key graphics and results are discussed in this section. Please refer to appendix B for the full details of the results.

### Dietary preferences

By 2015, nearly 12 million people in Canada are either vegetarian or striving to become vegetarian (Vancouver Humane Society), which roughly makes up for a third of the entire population. A highly motivating case study is therefore to compare a vegan to a meat lover. In the model, this is reflected by different ingredient lists. The vegan ingredient list consists of all kinds of vegetables, nuts, and fruits while the meat lover has all kinds of different fish or meat sources including eggs, cheese, and dairy products. The nutritional breakdowns for the vegan and meat-lover are shown below.




As expected, the vegan had only vegan dishes while the meat lover's list of recipes had a variety of meat choices such as Grilled California Chicken or Lasagna. The vegan also had a shorter total cooking time (130 min) compared to the meat lover (180 min) which made sense as meat dishes typically take longer to cook. Finally, the meat-lover's nutritional breakdown had roughly 10% more protein and 6% less fibre, which reflects their different dietary preferences quite reasonably.

### Age and activity level preferences

Another representative case study is a comparison between a young, active male and an old, sedentary female who are effectively at opposite ends of the spectrum in terms of calorie requirements. For a fair comparison, it is assumed that their personal preferences are identical and that they each have a fully stocked fridge. It is expected that the male consumes higher calories with possibly more protein and fat.

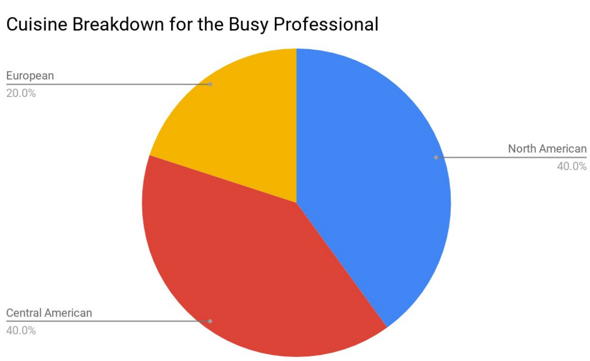
| | Young Active Male | Old Sedentary Female |
|---|---|---|
| **Total Calories** | 2600 kcal | 1202 kcal |
| **Recipe List** | Crockpot whole chicken<br>High protein stovetop skillet pizza<br>Lasagna<br>Grape gouda & arugula skewers<br>Guacamole with radish chips<br>Baba ganoush<br>Banana dessert sushi | Crispy pan-fried tofu<br>Hard-boiled eggs<br>Onion uttapam<br>Jicama chips<br>Creamy salsa and black bean nachos<br>Olive oil rice krispie treats<br>Parmesan crusted chicken<br>Frozen fruit pops |

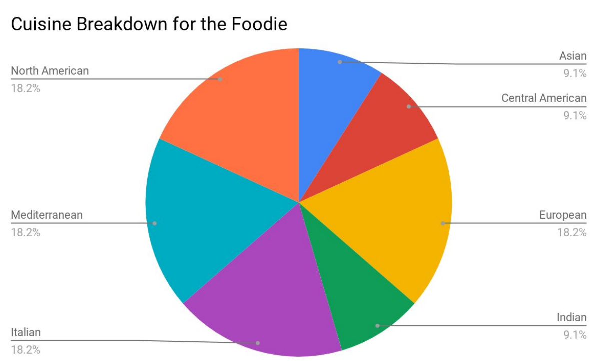
The recipe list of the old sedentary female consists mostly of light snacks in comparison to the male. Furthermore, the male consumes 2.1% more protein and 4% more fat (see appendix B), thus fulfilling both of the expectations at the outset of the case study. These differences in nutritional breakdowns, however, are relatively insignificant compared to the first case study, which suggests that total calories are indeed the most sensitive parameter to different age and activity levels as expected.

Lifestyles

A large part of the motivation for this project is to design a quick meal planner for someone who may not have a lot of time for cooking. Therefore, an appropriate case study is to compare a busy professional with an individual who in fact wants to take the time and make diverse dishes (aka. the "foodie"). Though both share the same personal preferences as well as fully stocked fridges, the busy professional wishes to spend no more than 1 hour combined for all his meals throughout the day and no more than 20 ingredients to limit the complexity of cooking. Therefore, it is expected that the busy professional will get relatively easier dishes while the foodie's recipe list will be significantly more diverse.

| | Busy Professional | Foodie |
|---|---|---|
| **Total Calories** | 1951 kcal | 2081 kcal |
| **Total Cooking Time** | 55 minutes | 238 minutes |
| **Number of Ingredients** | 20 | 47 |



Some of the recipes for the busy professional includes Easy Caprese Mac and Cheese and Easy Tortilla Chips, which aligns with the expectation. The busy professional also achieves a very similar level of optimality from meeting various nutrient recommendations despite much stricter restrictions on total cooking time and the number of ingredients, which is demonstrated partly by their similar calorie intakes as well as nearly-identical nutritional breakdowns (see appendix B). Furthermore, the foodie achieves a considerably greater diversity in cuisine types, befitting his title as the foodie. This case study therefore reflects the effectiveness of the model to plan a healthy, balanced diet for different lifestyles.

Ethnicity

Suppose now that the application has gained an international popularity and is used by two males from two very distinct geographical regions such as US and China. Even within Canada, this case study is an interesting test for the model as people are often encouraged to practice and uphold the traditions of their original ethnic background. The individuals in this case study vary only in their cuisine preferences; the US male prefers only North American cuisine while the Chinese male prefers only Asian dishes.

| | US | China |
|---|---|---|
| **Recipe List** | Banana and mango breakfast nice cream<br>Cajun shrimp<br>Steak marinade<br>Skillet pizza<br>Summer berries and banana smoothie | 15-minute lazy noodles<br>Crispy pan-fried tofu<br>Onigiri recipe (Japanese rice balls)<br>Thai salmon<br>Banana dessert sushi |

The US and Chinese individuals have the identical optimality score, suggesting that the model identified equally healthy, balanced diets for both users despite significant differences in cuisine preferences. It is discovered that the only notable difference between the two is the composition of their recipe list. As expected, nearly all of the dishes in the respective recipe list are distinctively North American for the US male and Asian for the Chinese male. Therefore, the model demonstrates its ability to tailor the meal plan according to cuisine preferences quite effectively.

## Conclusions & Future Directions

Several cases studies presented above validate model performance across various profiles ranging from dietary preferences to different ethnicities. The results accurately reflect differences in eating habits and lifestyles, demonstrating its effectiveness in catering to individual needs. The tool provides valuable insights that can be incorporated into growing user-centric applications such as ingredient tracking and grocery shopping  apps and smart fridges.

To improve the tool we have developed, standardized ingredient amounts and serving sizes could be used. This would make the resulting recipe list robust as it can suggest the amount of salad, main course or desserts to consume. By shifting attention to proper serving sizes, we can also extend the model to prepare meal plans for a week, instead of a day. A way to make the tool more personalized through continuous usage would be to predict new recipes that the user might want to try, given their previous cooking history and the ingredients that are commonly found in their household.

## References

Almost 12 Million Canadians Now Vegetarian Or Trying To Eat Less Meat! Vancouver Humane Society 2016. http://www.vancouverhumanesociety.bc.ca/almost-12-million-canadians-now-vegetarian-or-trying-to-eat-less-meat/.

Appendix 2. Estimated Calorie Needs per Day, by Age, Sex, and Physical Activity Level. Appendix 2 Estimated Calorie Needs per Day, by Age, Sex, and Physical Activity Level - 2015-2020 Dietary Guidelines. https://health.gov/dietaryguidelines/2015/guidelines/appendix-2/.

Appendix 7. Nutritional Goals for Age-Sex Groups Based on Dietary Reference Intakes and Dietary Guidelines Recommendations. Appendix 7 Nutritional Goals for Age-Sex Groups Based on Dietary Reference Intakes and Dietary Guidelines Recommendations - 2015-2020 Dietary Guidelines. https://health.gov/dietaryguidelines/2015/guidelines/appendix-7/.

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Yummly Recipe APIDocumentation. Yummly | Documentation.

https://developer.yummly.com/documentation.

## Appendix A1: MATLAB Tool Implementation

To access the optimization tool, please download the main source file ("aia.m"), solver function ("MIE465Optimize_New"), recommended nutrition data ("MaleValues.csv", "FemaleValues.csv"), and the recipes data ("aggregateData.csv") contained in this Google Drive folder:

https://drive.google.com/open?id=1PNMja_Vnt-zqYV5CNhMXVAyJ9Ykev0jN

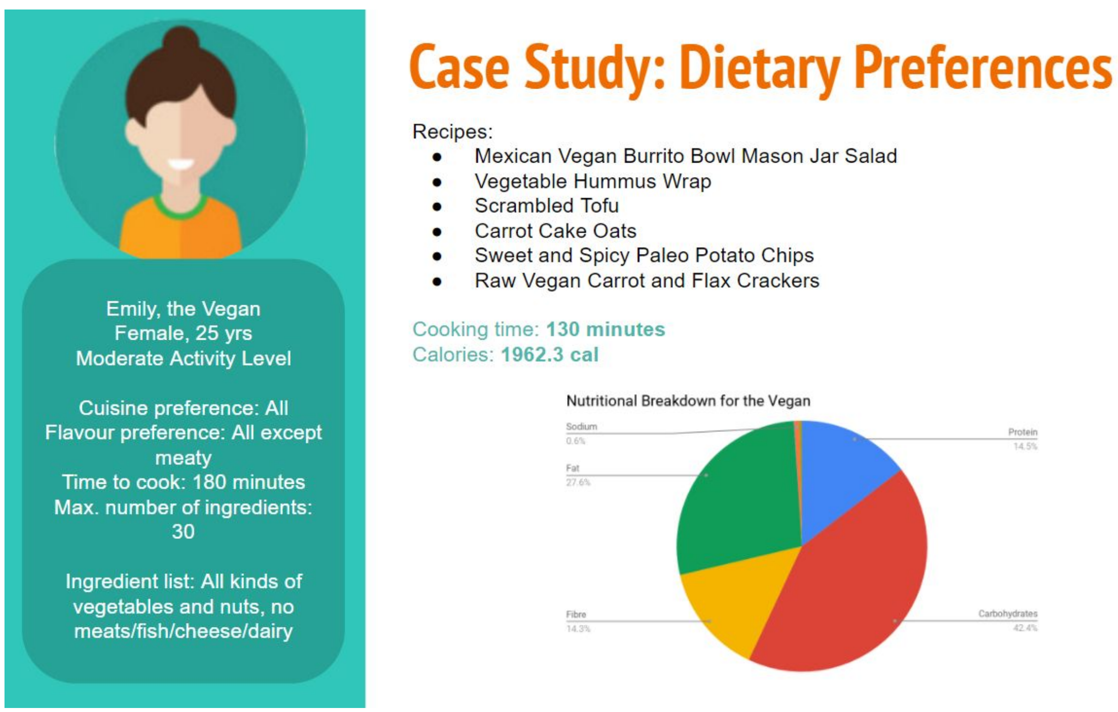
## Appendix A2: Python Data Fetching & Cleaning Implementation

For any inquiries into programming practices or methods, and the code used to fetch the Yummly data recipes, as well as to perform the data cleaning tasks can be accessed below:

https://drive.google.com/open?id=1PKla6qV62xNtoMi1gpW7r_OIJuZpmp1c

## Appendix B: Detailed results of case studies

Dietary preferences:

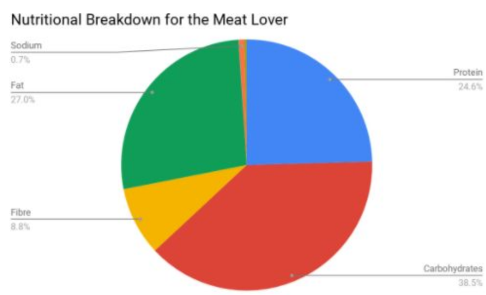


# Case Study: Dietary Preferences

Recipes:

- Turkey Avocado & Feta Combo
- Grilled California Chicken
- Lasagna
- Poached Eggs
- Polish Potato Pancakes
- Soft Pretzels with Cheese Sauce
- Homemade Tortilla Chips

Cooking time: **170 minutes**
Calories: **1971.1 cal**

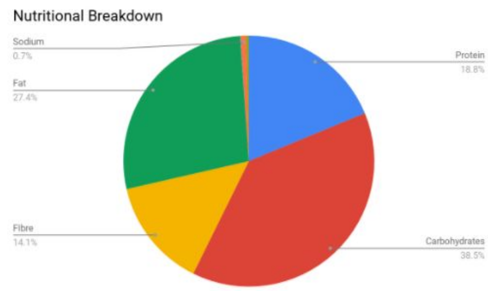



<u>Age and activity level preferences:</u>


## Case Study: Age & Activity Levels

Recipes:
- Crockpot Whole Chicken
- High Protein Stovetop Skillet Pizza
- Lasagna
- Grape Gouda & Arugula Skewers
- Guacamole with Radish Chips
- Baba Ganoush
- Banana Dessert Sushi

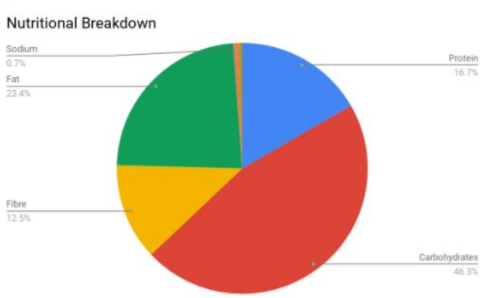
Calories: **2600 cal**

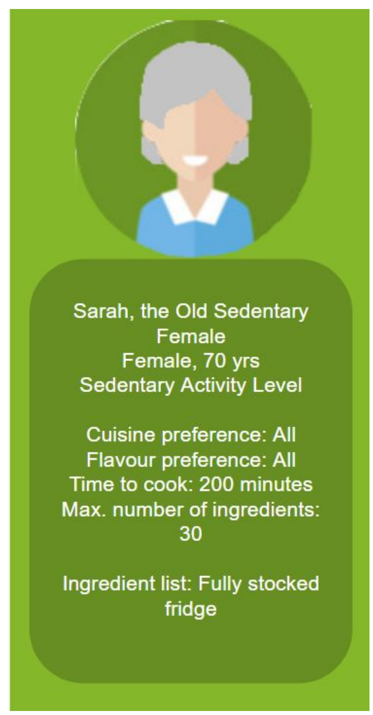



## Case Study: Age & Activity Levels

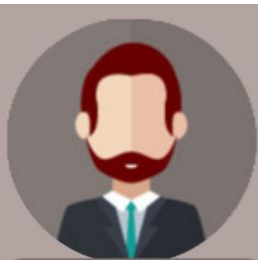
Recipes:
- Crispy Pan-fried Tofu
- Hard-boiled Eggs
- Onion Uttapam
- Jicama Chips
- Creamy Salsa and Black Bean Nachos
- Olive Oil Rice Krispie Treats
- Parmesan Crusted Chicken
- Frozen Fruit Pops

Calories: **1202 cal**



<u>Lifestyle preferences:</u>



Jim, the Busy Professional
Male, 40 yrs
Moderate Activity Level

Cuisine preference: All
Flavour preference: All
Time to cook: 60 minutes
Max. number of ingredients: 20

Ingredient list: Fully stocked fridge

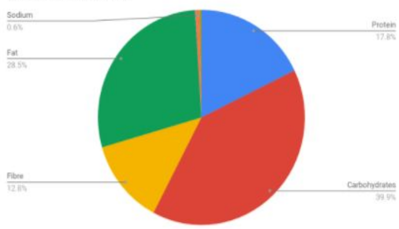
## Case Study: Lifestyles

Recipes:

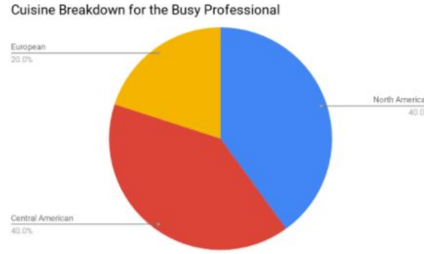
- Avocado Salad with Heirloom Tomatoes
- **Easy** Caprese Mac and Cheese
- **Easy** Homemade Tortilla Chips
- French Omelette
- Sleepy Blueberry Muffin Smoothie

Total Cooking Time: **55 minutes**
Total Number of Ingredients Used: **20**
Calories: **1951 cal**

Nutritional Breakdown




Cuisine Breakdown for the Busy Professional



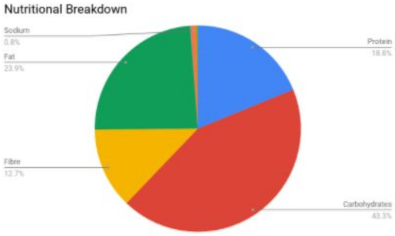

## Case Study: Lifestyles

Recipes:

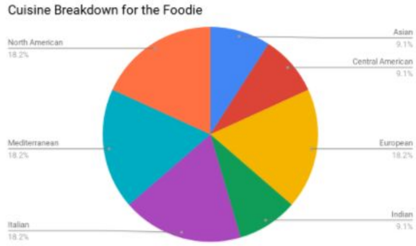
- Spinach and Red Pepper Mini Frittatas
- Garam Masala Tofu Scramble
- Zucchini Noodles with Lemon-Garlic Spicy Shrimp
- Onigiri
- Mexican Street Corn Style Popcorn
- Broiled Grouper with Lemon and Thyme
- Vegetable Hummus Wrap
- French Omelette
- Frozen Fruit Pops
- Italian Tuna Salad
- Homemade Applesauce

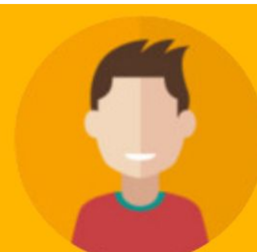
Total Cooking Time: **238 minutes**
Total Number of Ingredients Used: **47**
Calories: **2087 cal**

Nutritional Breakdown




Cuisine Breakdown for the Foodie



Andrew, the Freelance Food Critic
Male, 40 yrs
Moderate Activity Level

Cuisine preference: All
Flavour preference: All
Time to cook: 300 minutes
Max. number of ingredients: 50

Ingredient list: Fully stocked fridge