A re-examination of the MPP from a multiobjective optimization perspective

The *SHARP* approach

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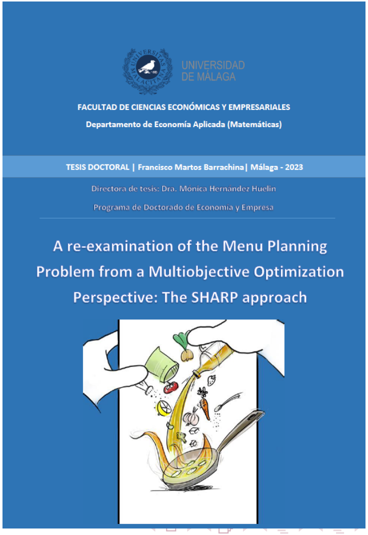

The Problem of What to eat?

Given a list of available food items, with nutritional properties and a cost:

- How much of each should I eat to be well nourished?
- Is it enough for it to be as cheap as possible?
- How important it is that I like it?
- Could I avoid the items I am allergic to?
- What about including locally produced items?

The Menu Planning Problem (MPP): Ingredients and Dishes.

However, we do not eat raw food in bulk, do we?

Salmorejo

The Menu Planning Problem.

It was **introduced in the 1960s** by Balintfy[1] as an evolution to the Diet Problem formulated by George Stigler[2].

- The aim is to find **the cheapest possible diet** that satisfies certain **nutritional requirements**.
- Instead of an array of raw foods, it employs cooked dishes as (integer) variables. Where x_n represent the number of times a dish n is chosen from a list of N dishes.
- These variables are substituted in current approaches of the problem with **binary variables** with a given structure of D days and K intakes (slots) per day.

[1] Balintfy 1964.

[2] Stigler 1945.

The basic Menu Planning Problem with Binary Variables.

The Optimisation Model **could still** look like this:

$$
\begin{aligned}
Cost : \min_{x_n} \quad & \sum_{d=1}^{D}\sum_{k=1}^{K}\sum_{n=1}^{N} c_n \cdot x_n^{k,d} \\
\text{s.t.} \quad & x_n^{k,d} \in X \\
& x_n^{k,d} \;\; binary \;\; \forall\, n, k, d
\end{aligned}
$$

Where:

- X is just bounded by basic nutritional constraints.
- D is the number of days in the schedule and K the number of daily intakes.
- c_n is the cost (in $) per intake menu item (dish) n.
- $x_n^{k,d}$ is now a binary variable fitting a given schedule, $x_n^{k,d} = 1$ if dish n is consumed in the k intake of day d and $x_n^{k,d} = 0$ otherwise.

It can be used for:

- **Hospitality industry:** designing nutritious, affordable, and varied weekly menus for food providers.
- **Institutional catering:** adapting menus to dietary restrictions and health conditions in prisons, hospitals and elderly care homes.
- **Policy making and dietary recommendations:** optimizing population health over long planning horizons, while considering cultural background.
- **Transportation:** planning compact, safe, and well stored meals.
- **Personalized diets:** generating individual meal plans based on user preferences.
- **Sustainable food systems:** incorporating environmental criteria such as carbon footprint or food waste minimization.

The Literature of the MPP.

State of the art in the current age of computation, we have:

- Use of binary variables that fit into the schedule.[3]
- Taking into account objectives beyond cost, especially, sustainability.[4]
- Multiple conflicting objectives together.[5]
- Different sets constraints, to accommodate allergies, diseases or lifestyles.[6]
- A complex problem in need of metaheuristics.[7]
- Solve the problem for small parts of a schedule in the Food Industry.[8]

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[3] Benvenuti et al. 2016.
[4] García-Leal, Espinoza Pérez, and Vásquez 2023; Gustafson et al. 2022.
[5] Sundin et al. 2023; Ramos-Pérez et al. 2020.
[6] Marty et al. 2022; Maillot et al. 2009.
[7] Martos-Barrachina et al. 2022; Hernandez-Ocana et al. 2018; Moreira et al. 2018.
[8] Segredo et al. 2020; Aggarwal et al. 2020; Benvenuti and De Santis 2020.

SHARP Framework.

SUSFANS developed an European Framework for Improving EU eating towards **Sustainable Diets.**[a].

- Introduced the SHARP acronym:
  - **S**ustainability.
  - **H**ealth.
  - **A**ffordability.
  - **R**eliability.
  - **P**alatability.

[a] Ivancic et al. 2018.

The 5 Dimensions: A few notes.

The two basic dimensions are **Health and Affordability**, already introduced by George Stigler in 1945 and used by every research since then.

- The set of constraints ensures proper nutrition, and therefore health.
- Cost is the most used objective function.

The 5 Dimensions: A few notes.

Palatability refers to the 'likeability' or 'acceptability' of the proposed diets. But how is this measured?
It is tackled implicitly, through the use of acceptable recipes, likeable items or through distance metrics in the continuous approach.[9]

[9] Kanellopoulos et al. 2020; Perignon et al. 2016; Benvenuti and De Santis 2020; Hernández et al. 2021.

The 5 Dimensions: A few notes.

Sustainability is considered mainly in terms of environmental impact.[10] It has become a very important aspect in most current approaches of the problem.

Food security, market availability and supply chain trustworthiness are encompassed in **Reliability**. It is either not considered or considered implicitly.
Is this guaranteed in our European Context? Yes, but...

[10] Bussel et al. 2019.

Why sustainability in the food system?

The global food industry is an economic titan[11]:

- It accounts for around 12% of global GDP (10 trillion $).
- It accounts for around 40% of global employment.
- Its negative externalities are worth 14% of global GDP (12 trillion $).
- Externalities such as human health, social impact and environmental damage.

[11] WEF 2020.

Why sustainability in the food system?

GHGE

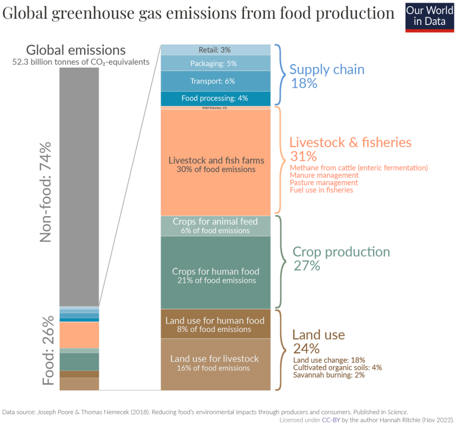

Figure: Food Contribution to GHGE.

Why sustainability in the food system?
Land

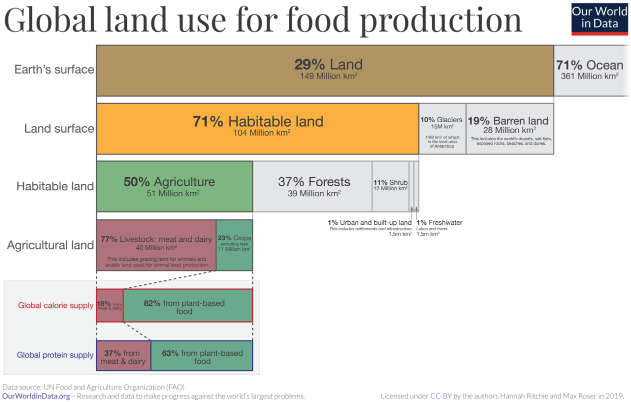

Figure: The use of land for food.

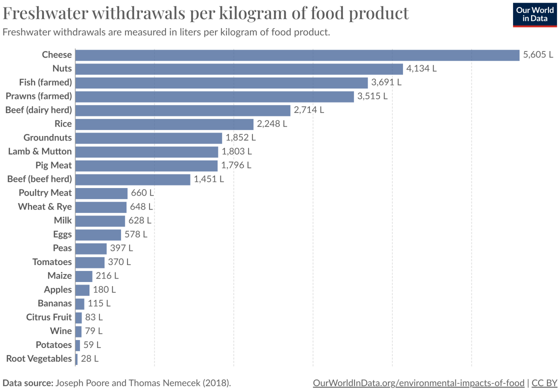

Figure: The use of water per kg of food.

Our Work.

Our **objective** is to create a flexible multiobjective optimization model for the MPP within the SHARP framework.

1. Understanding the Spanish Diet (DP).[12]
2. Improving it considering the Mediterranean Diet Standards (DP).[13]
3. Developing a preliminary Menu Planning model **H**ealthy and **R**eliable.[14]
4. Using **C**ost and **P**alatability as objectives.[15]
5. Incorporating a **S**ustainable objective and solve the multi-objective problem.[16]

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[12] Martos-Barrachina et al. 2019.

[13] Hernández et al. 2021.

[14] Martos-Barrachina et al. 2022.

[15] Martos-Barrachina, Delgado-Antequera, and Hernández 2024.

[16] Martos-Barrachina 2024.

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The Spanish Diet: How close is it to the MD?

A dataset was developed with data from a Spanish Consumption Panel for 2016 and 2017 (MAPAMA)[a]. The data is dissaggregated by region, month and food group.

An analysis of the different regional diets of Spain (annually and by seasons) employing a two-step clustering algorithm with **Ward's hierarchical method** and **k-means**, including the Mediterranean Diet 'as a region'.[b]

[a] MAPAMA 2018.

[b] Martos-Barrachina et al. 2019.

Patrones de Consumo de Alimentos en España

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RESUMEN:

España se ha considerado una de las regiones de referencia de la Dieta Mediterránea, conocida por su contribución a la mejora en la calidad de vida. Esta dieta se caracteriza por el consumo de aceite de oliva, productos frescos, vino tinto, más pescado que carne y pocos alimentos procesados. Nuestro objetivo es conocer las pautas de consumo de la población española general y sus distintas regiones, analizando cómo pueden agruparse y su grado de adherencia a la Dieta Mediterránea.

A este respecto, además de un análisis descriptivo del consumo de cada región española y de cada grupo de alimentos, se realiza un análisis de conglomerados en dos etapas usando el método jerárquico de Ward y el método de K-medias para clasificar las regiones españolas en base al consumo alimentario.

Adicionalmente, se analizará la adherencia de la dieta española a la Dieta Mediterránea. La variable, "patrón de consumo de la Dieta Mediterránea" se compara con las distintas regiones españolas. Es difícil, en virtud de los resultados situar las pautas de consumo actuales en España dentro de los estándares de la Dieta Mediterránea.

Palabras Clave: Dieta Mediterránea, Consumo en España, Clusterización, Ward, K-Medias

ABSTRACT:

Spain has been considered as a reference of the Mediterranean Diet, known for its contribution to a higher life quality. This diet is reknown for its consumption of olive oil, fresh foods, red wine, more fish than meat and the absence of processed foods. Our goal is to know the consumption pattern of the Spanish population and the different Spanish regions, comparing them and measuring their adherence to the Mediterranean Diet.

Therefore, apart from the descriptive analysis of the food intakes of every Spanish region by food group, a cluster analysis in two stages is performed, using both the hierarchical Ward's method and the k-means to clasify the Spanish regions by their food consumption.

Additionaly, the adherence of the Spanish diet to the Mediterranean Diet is studied. The 'Mediterranean Diet consumption pattern' is compared to the Spanish regions. It is hard to conclude that the current counsumption patterns in Spain are within the standards of the Mediterranean Diet.

Keywords: Mediterranean Diet, Consumption, Spain, Clustering, Ward, K-Means.

Improving the Spanish Diet using the MD.

The next work proposes a continuous optimization problem to improve the Spanish diet with Goal Programming. For doing so, it uses **Reference Point methodology** and a Tchebycheff Distance Metric, considering a nutritious feasible region and the Mediterranean Diet as a reliable proxy for increased health, reliability and palatability.[a]

[a] Hernández et al. 2021.

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ORIGINAL PAPER

Check for updates

Using multiobjective optimization models to establish healthy diets in Spain following Mediterranean standards

Mónica Hernández[1] · Trinidad Gómez[1] · Laura Delgado-Antequera[1] · Rafael Caballero[1]

Received: 17 December 2018 / Revised: 13 May 2019 / Accepted: 27 May 2019

Abstract
Last reviews show how the Spanish consumption patterns have become away from the Mediterranean diet, traditionally consumed in Spain and widely supported by the nutritional expert community. Hence, the aim of this study is to explore and provide different alternatives to the current Spanish diet. The idea is to obtain a set of palatable diets fulfilling the nutritional requirements and conform the Mediterranean standards, while staying as close as possible to the current population pattern, under a budget constraint. In this context, different models are developed using multiobjective techniques. Additionally, this work defines an alternative diet more stable in comparison with the diets on the boundary of the feasible set. The consumption data used in this study is taken from *Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente* (in Spanish MAPAMA) that contains relevant information about the foods consumed in Spain. Using this data, each model has been solved with Matlab Software, obtaining different feasible diets, whose composition corresponds to the suggested daily intake for a Spanish adult. In any case, the budget constraint reduces the current cost and fulfills the nutritional requirements, attending to the Mediterranean standards. Results show different food baskets to guide the current Spanish diet towards the consumption of healthy foods in the appropriate proportions, going back to the diet traditionally consumed.

Keywords Dietary patterns · Mediterranean diet (MD) · Goal Programming · Weighted Tchebycheff metric

Mathematics Subject Classification 90C29 · 90C90

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To model the MPP we need:

- Computational tools (we used Matlab).
- A set of (I=300) ingredients and (N=300) recipes.
- A schedule of (D=15) days with (K=12) intakes each.
- Our variables ($X_n^{d,k}$, where $X_n^{d,k} = 1$ if the n^{th} recipe is consumed in the k^{th} slot of day d^{th} and $X_n^{d,k} = 0$ otherwise)
- A set of constraints that includes at least nutrition, and MD standards.[17].
- An individual profile to set the specific values of these constraints (Active woman in her 30s).[18].
- **To find the feasible region** in order to explore it.
- And objectives, such as cost, palatability or sustainability.

[17] Moreiras et al. 2016.

[18] Moreiras et al. 2016.

Labelling and Nutritional Data

- The recipe dataset includes **300 dishes**, each defined by a list of ingredients[19].
- Ingredients ($I = 300$) are **characterized by their nutritional profiles**.
- Both ingredients and dishes are **categorized into food groups and subgroups**[20].
- Each dish is assigned a **main ingredient**, which determines its group classification.
- Dishes are also **labelled by the meal intake** (k) they belong to (e.g., breakfast, lunch, supper).

[19] MAPAMA 2018.

[20] Moreiras et al. 2016.

Nutritional and Food Constraints in the MPP

We set lower boundaries ($b_{L,j}$) and upper boundaries ($b_{U,j}$) for constraints concerning:

- **Macronutrients** (as percentage of total energy):
  - Protein, Carbohydrates, Sugar, Fat (including fat quality)
- **Micronutrients and other nutritional factors** (daily intake):
  - Energy, Fiber, Cholesterol, Calcium, Iron, Magnesium, Sodium, Potassium, Phosphorus
  - Niacin, Folate, Vitamin B12, Vitamin C, Vitamin A, Vitamin D, Vitamin E
  - Water
- **Food items and groups** (Mediterranean Diet recommendations):
  - Red meat, Processed meat, Fish
  - Vegetables, Fruit, Legumes, Nuts
  - Extra virgin olive oil (EVOO), Butter
  - Sweets

Last constraints for the model.

These constraints regard common sense, repetition and balance[21]:

- Throughout the menu.
- Throughout the day.
- Dish labelling.

[21] Martos-Barrachina et al. 2022.

Structure of Daily Meals and Portion Sizes

- **Daily meal structure:**
  - **Breakfast:** hot beverage, fruit or juice, breakfast dish.
  - **Lunch:** bread, cold drink, starter, main dish, dessert.
  - **Supper:** cold drink, dinner dish, dessert.
  - **Extras:** snacks may be included optionally.
- **Standardized portion sizes (C_n):**
  - Main dishes: approx. 200–250g
  - Bread, fruit, desserts, nuts: standardized weights (e.g., 100g fruit, 30g nuts)
  - Beverages: defined by volume (e.g., 200–250ml for cold drinks)

Finding the Feasible Set.

Initially, we use an Extended Tchebycheff Function (ETF) to consider the distance between any non-feasible solution and the feasible set.

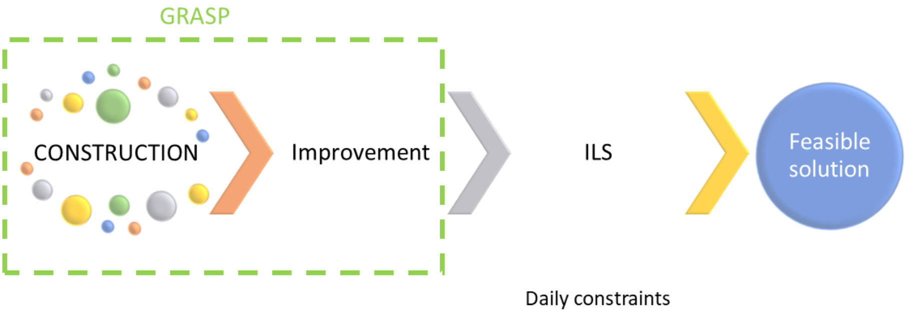
$$\min_{x_n}\{\ \max_{n=1\ldots N}\{\sum_{j\in R_U}\frac{1}{b_{U,j}}(A_{j,n}\cdot Q_n-b_{U,j}),\sum_{j\in R_L}\frac{1}{b_{L,j}}(b_{L,j}-A_{j,n}\cdot Q_n)\}$$
$$+\rho\cdot(\sum_{j\in R_U}\frac{1}{b_{U,j}}(A_{j,n}\cdot Q_n-b_{U,j})+\sum_{j\in R_L}\frac{1}{b_{L,j}}(b_{L,j}-A_{j,n}\cdot Q_n))\} \quad (1)$$

It represents the collection of would-be constraints, where:

- $Q_n = C_n \cdot \sum_{d=1}^{D}\sum_{k=1}^{K} X_n^{d,k} \quad \forall n = 1, 2, \ldots N$
- A is the matrix of coefficients of the constraints.
- $A_j \cdot Q$ is the result obtained for constraint j.
- b_U and b_L stand for the Upper and Lower bounds.

Generating Seeds.

This function is optimized using a GRASP+ILS procedure.



And now, let's solve it.

We are able to solve the feasibility problem. This work is published in ORIJ (JCR Q2 - Cat: MS & OR). This left us with around 30.000 unique feasible menus, ready to take the next steps and solve the problem for any specific objective function.[a]

[a] Martos-Barrachina et al. 2022.

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ORIGINAL PAPER

Check for updates

An extensive search algorithm to find feasible healthy menus for humans.

F. Martos-Barrachina[1] · L. Delgado-Antequera[1] · M. Hernández[1] · R. Caballero[1]

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Abstract
Promoting healthy lifestyles is nowadays a public priority among most public entities. The ability to design an array of nutritious and appealing diets is very valuable. Menu Planning still presents a challenge which complexity derives from the problems' many dimensions and the idiosyncrasies of human behavior towards eating. Among the difficulties encountered by researchers when facing the Menu Planning Problem, being able of finding a rich feasible region stands out. We consider it as a system of inequalities to which we try to find solutions. We have developed and implemented a two-phase algorithm -that mainly stems from the Randomized Search and the Genetic- that is capable of rapidly finding an pool of solutions to the system with the aim of properly identifying the feasible region of the underlying problem and proceed to its densification. It consists of a hybrid algorithm inspired on a GRASP metaheuristic and a later recombination. First, it generates initial seeds, identifying best candidates and guiding the search to create solutions to the system, thus attempting to verify every inequality. Afterwards, the recombination of different promising candidates helps in the densification of the feasible region with new solutions. This methodology is an adaptation of other previously used in literature, and that we apply to the MPP. For this, we generated a database of a 227 recipes and 272 ingredients. Applying this methodology to the database, we are able to obtain a pool of feasible (healthy and nutritious) complete menus for a given D number of days.

Keywords Multi-criteria programming · Heuristic integer programming · Algorithms · Menu planning problem · Inequality system

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Focusing on what we like.

- Do we know what diets are healthy?
- Why don't we eat healthier?[22]
- How can you ensure that a diet is going to be followed?
- Do we accept a healthy diet if we do not like it?
- What if we consider the healthy diet to be too expensive?
- Is acceptability measurable in the context of the MPP?

[22] De Leon, Jahns, and Casperson 2020.

Including Palatability.

We needed to measure palatability!

we devised a similarity function to evaluate how similar any to menus a and b are to each other.

$$Sim(M_a, M_b) = \frac{P_{a,b} + I_{a,b} \cdot w_I + SG_{a,b} \cdot w_{SG} + G_{a,b} \cdot w_G}{D \cdot K} \quad (2)$$

- $Sim(M_a, M_b)$ is the similarity between Menu plans M_a and M_b.
- $P_{a,b}$ is the number of plates (dishes) in common between M_a and M_b:

$$P_{a,b} = \sum_{n=1}^{N} min\{F^n{}_a, F^n{}_b\}$$

- $I_{a,b}$, $SG_{a,b}$, $G_{a,b}$ are the number of plates (dishes) that share a common main ingredient, its subgroup, or its group between M_a and M_b, excluding the coincidences in previous categories.
- w_I, w_{SG}, w_G are the weights that represent how acceptable the change between two plates (dishes) that share the main ingredient, its subgroup, or its group is. The higher it is, the more palatable the change is.

Including Palatability and Affordability.

We start with a consumer and their current consumption (denoted as CM or RM, usually non-feasible), and try to offer solutions that are very similar to this one.

k	Meal\Day	Day 1	Day 2	Day 3	Day 4	Day 5
1	BF Drink	Unsweetened semi-skimmed coffee with mil	Unsweetened semi-skimmed coffee with mil	Unsweetened semi-skimmed coffee with milk	Unsweetened semi-skimmed coffee with milk	Unsweetened semi-skimmed coffee with milk
2	BF Main	Cooked ham smurf with oil and tomato	Cereal bowl with semi-skimmed milk	Cooked ham and cheese sandwich	Butter and jam toast	Cooked ham smurf with oil and tomato
3	BF Fruit	Orange & Carrot Juice	Orange & Carrot Juice	Orange & Carrot Juice	Watermelon and Strawberry Juice	Watermelon and Strawberry Juice
4	Lunch Bread	White Bread Bun (100g)	White Bread Bun (100g)	Whole Wheat Bread Bun (100g)	Whole Wheat Bread Bun (100g)	Whole Wheat Bread Bun (100g)
5	Lunch Drink	Glass of soda	Water	Glass of wine	Glass of soda	beer can
6	Lunch 1st	Chicken and Vegetable Paella	Chicken and Vegetable Paella	Malaga Salad	Malaga Salad	Onion soup
7	Lunch 2nd	Grilled aubergines	Grilled mushrooms	Sirloin steak with Pedro Ximenez (*add broth) with Fr	Simple Spinach Salad	Grilled asparagus with mayonnaise
8	Lunch Desse	Orange, Pineapple and Strawberry Juice	Portion of Plums	Yoghurt	Portion of Plums	Coconut Rations
9	Dinner Drink	Small beer	Beer can	Glass of wine	Glass of soda	Glass of wine
10	Dinner Main	Grilled sea bream with mixed salad	Grilled cod with mixed salad	Grilled cod with mixed salad	Sautéed asparagus with garlic	Grilled asparagus with mayonnaise
11	Dinner Desse	Rations of strawberries	Yogurt with nuts	Yogurt with cereals	Mango Serving	Yogurt with nuts
12	Break Nuts	Almonds	Mixed nuts	Peeled walnut	Almonds	Salted fried peanuts

k	Meal\Day	Day 6	Day 7	Day 8	Day 9	Day 10
1	BF Drink	Unsweetened semi-skimmed coffee w/milk	Unsweetened semi-skimmed coffee with mil	Unsweetened semi-skimmed coffee with milk	Unsweetened semi-skimmed coffee with milk	Unsweetened semi-skimmed coffee with milk
2	BF Main	Butter and jam toast	Cooked ham smurf with oil and tomato	Cereal bowl with semi-skimmed milk	Bread with oil	Cooked ham smurf with oil and tomato
3	BF Fruit	Watermelon and Strawberry Juice	Apple & Grape Juice	Orange & Carrot Juice	Serving of Raspberry	Orange & Carrot Juice
4	Lunch Bread	Whole Wheat Bread Bun (100g)	White Bread Bun (100g)	White Bread Bun (100g)	White Bread Bun (100g)	Whole Wheat Bread Bun (100g)
5	Lunch Drink	Glass of soda	beer can	Small beer	Beer can	Beer can
6	Lunch 1st	Vegetable soup	Onion soup	Paella chicken and rabbit	Cream of zucchini soup	Malaga Salad
7	Lunch 2nd	Pil pil tofu with mixed salad and rice	Garlic rabbit with potatoes	Fried anchovies with mixed salad	Sirloin steak with Pedro Ximenez (*add broth) with French fri	Grilled lamb chop with French fries
8	Lunch Desse	Portion of Pomegranate	Serving of watermelon	Summer Fruit Mix	Portion of melon	Custard
9	Dinner Drink	Glass of soda	Beer can	Beer can	Glass of wine	Glass of wine
10	Dinner Main	Simple Swiss Chard Salad	Grilled tuna with mixed salad	Sautéed asparagus with garlic	Grilled sole with mixed salad	Grilled cod with mixed salad
11	Dinner Desse	Yogurt with nuts	Rations of strawberries	Mango Serving	Mango Serving	Portion of melon
12	Break Nuts	Mixed nuts	Almonds	Hazelnut	Mixed nuts	Hazelnut

k	Meal\Day	Day 11	Day 12	Day 13	Day 14	Day 15
1	BF Drink	Unsweetened semi-skimmed coffee with mil	Soluble Cocoa with Semi-Skimmed Milk	Unsweetened semi-skimmed coffee with milk	Unsweetened semi-skimmed coffee with milk	Unsweetened semi-skimmed coffee with milk
2	BF Main	Cooked ham and cheese sandwich	Bread with oil	Yogurt with cereals	Cereal bowl with semi-skimmed milk	Bread with oil
3	BF Fruit	Banana Serving	Banana Serving	Orange, Pineapple and Strawberry Juice	Orange & Carrot Juice	Apple & Grape Juice
4	Lunch Bread	Whole Wheat Bread Bun (100g)	White Bread Bun (100g)	White Bread Bun (100g)	White Bread Bun (100g)	Whole Wheat Bread Bun (100g)
5	Lunch Drink	Beer can	Beer can	Beer can	Water	Glass of wine

Our optimization model then is:

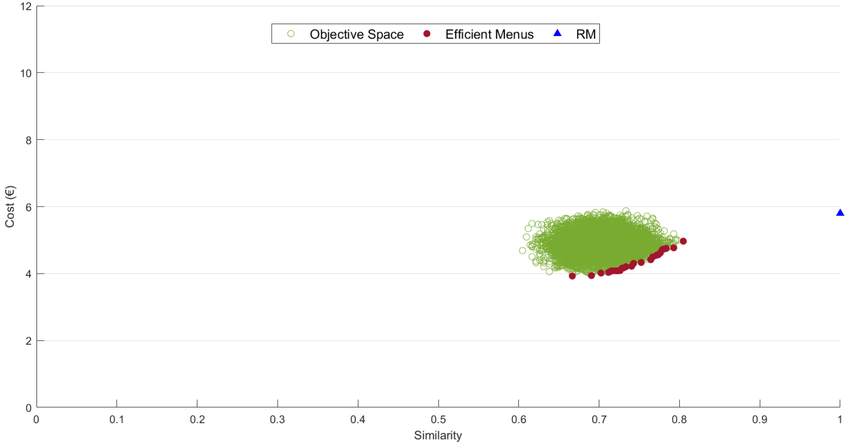
$$
\begin{aligned}
Cost: \quad & \min_{x_n} \quad c(x_n^{k,d}) = \sum_{d=1}^{D}\sum_{k=1}^{K}\sum_{n=1}^{N} c_n \cdot x_n^{k,d} \\
Palat: \quad & \max_{x_n} \quad p(x_n^{k,d}) = Sim(M_a, CM) \\
& \text{s.t.} \quad x_n^{k,d} \in X \\
& \qquad\;\; x_n^{k,d} \;\; binary \;\; \forall\, n, k, d
\end{aligned}
$$

Where:

- X is bounded by schedule, labels, nutritional, repetition and MD constraints.
- M_a is the menu formed by variables $x_n^{k,d}$.
- CM is the current menu of a given consumer, to which we try to be similar

Including Palatability and Affordability.

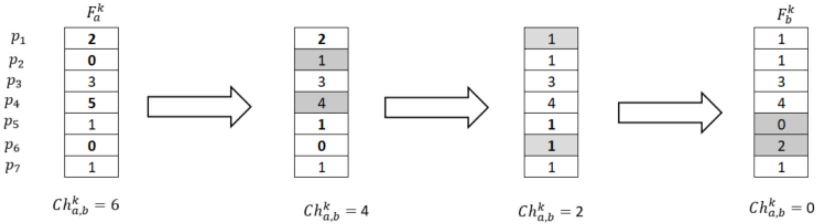
Figure: The preliminary feasible set in the objective space.



We start with a consumer and **their current consumption** (denoted as CM or RM, usually non-feasible), and use a Path Relinking Algorithm[23] with feasible solutions as guiding seeds to move it towards the feasible region.

[23] Sánchez-Oro et al. 2021.

Including Palatability and Affordability: Path Relinking

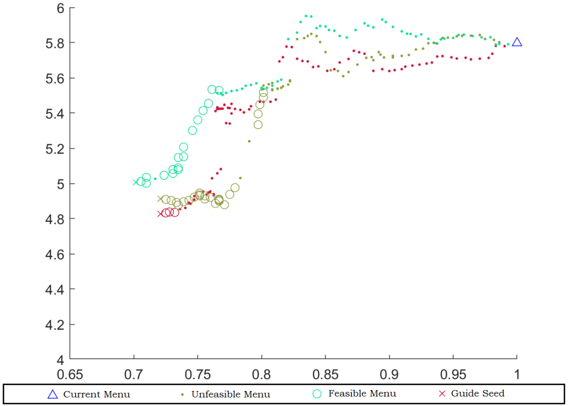


For the starting Menu *a* and guiding Menu *b*, we generate *k* frequency vectors for each, F_a^k and F_b^k, compute the number of changes $CH_{a,b}^k$ to transform F_a^k and F_b^k, and do so, using the Path Relinking with three approaches:

- Looking for more feasible solutions.
- Moving the CM towards the feasible region.
- Densifying the Pareto Front.

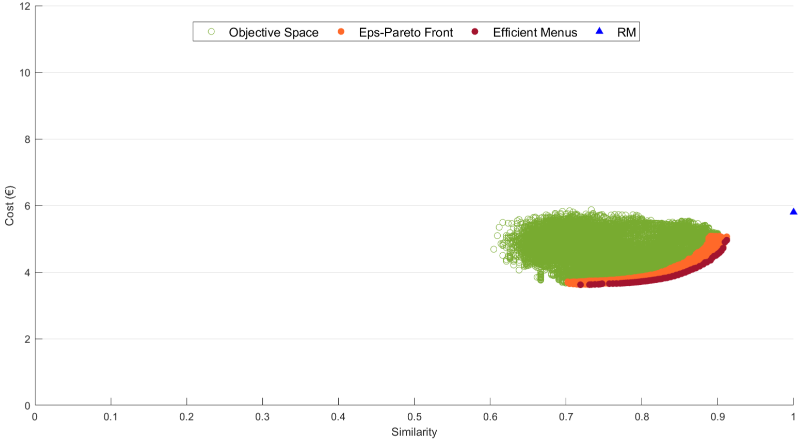
Including Palatability and Affordability

Figure: Moving the Current Menu towards the feasible region



Including Palatability and Affordability

Figure: Feasible Set with Pareto Region and ϵ-Pareto Front Objective Space



This work is published in JORS (JCR Q2 - Cat: MS & OR). We were able to populate the feasible region and to find a dense Pareto Front and Epsilon Pareto Front in the bi-objective Cost-Palatability problem.[a]

[a] Martos-Barrachina, Delgado-Antequera, and Hernández 2024.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ORIGINAL ARTICLE

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A novel cost-palatability bi-objective approach to the menu planning problem with an innovative similarity metric using a path relinking algorithm

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ABSTRACT
Bad eating habits are considered with low exercise, tobacco, and alcohol use, among the greatest health risk factors in high-income countries. Here, the spread of non-communicable diseases related to diet contrasts with the increasing availability of diet guidelines and health information. We are all left wondering, why are we not eating healthier? Palatability and cost appear as the two most important barriers to adherence to any prescribed diet.

This work aims to generate high-adherence healthy menus attending to Mediterranean standards, modelling and solving a cost palatability bi-objective optimisation problem. Although the latter is implicitly considered in most current models, its use as a quantifiable objective is novel. For this, a novel Similarity Function is introduced, which evaluates the proximity of two different menus and returns a similarity metric between 0 and 1. A multi-criteria optimisation method is used to design nutritious menu plans and analyse the trade-off between the cost and palatability of menus. A Path Relinking algorithm is later applied to improve the objective values, with specific considerations to palatability, designing healthy menus that can beat those adherence barriers.

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KEYWORDS
Combinatorial optimisation; multi-criteria decision making; menu planning problem; path relinking

1. Introduction

Nowadays, the promotion of a healthy lifestyle is a goal among governments all around the world. Policies to ensure the population's habits shift towards exercising and an optimal diet are currently—and have been for the last 20 years—the norm at local, regional, and national levels in most developed countries (Bröckling, 2010). However, if we compare this ideal goal to the number of malnourished people, the conclusion is embarrassing. Why are we not listening to the experts and eating healthier? Time, preference, and cost have been recently identified as the core barriers to diet adherence (De Leon et al., 2020).

The mathematical modelling of the Diet Problem (DP) starts with Stigler (1945) and Dantzig (1963). Originally, raw ingredients—continuous—were combined to satisfy nutritional constraints and minimise cost. However, none of their models provided an edible solution. The need for a diet pattern that is also palatable became evident. It was first introduced as a set of "common sense" constraints by Smith (1959) including paired and likable products.

The Menu Planning Problem (MPP) is the evolution from the DP into a large combinatorial problem, where variables are recipes to be consumed in a schedule, and was introduced by Balintfy (1964). Texture, colour, and other aesthetic features were included to increase palatability (Gue, 1969). Similar works followed applying the problem to different contexts (Romero & Rehman, 1984; Fletcher et al., 1994; Leung et al., 1995). Currently, there are a few trends in implementing menus mainly for institutions such as schools (Moreira et al., 2018; Segredo et al., 2020) or hospitals (Aggarwal et al., 2020).

The arrival of the computation era allowed for the inclusion of new objectives and constraints and the use of a variety of algorithms that efficiently find solutions to both the DP and the MPP. For instance, Seljak (2009) used the Elitist Non-Dominated Sorting Genetic Algorithm in a multi-level way to solve the Multidimensional Knapsack Problem of Menu Planning. In the work of Syahputra et al. (2017), a Genetic Algorithm schedules diets for diabetic patients. Marrero et al. (2020) compared the use of a Memetic Algorithm (MA)—also used by Segura et al. (2019)—and an Iterated Local Search combined with a Multi-Objective Evolutionary Algorithm based on Decomposition (ILS-MOEA/D) to generate lunch menu plans for a school cafeteria, while Hernandez-Ocana et al. (2018) used a Two Swim Modified Bacterial

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And now, towards including Sustainability

How do we continue to work on the MPP?

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1. Introduction.
2. The Spanish Diet and the MD.
3. The Feasibility Problem.
4. The Palatability-Cost Problem.
5. Including Sustainability.
6. Conclusion and Future Lines. (EN)

Considering Sustainability

- When sustainability is included as an objective —through greenhouse gas emissions (GHGE), water consumption, or land usage— the problem becomes a much more interesting **multi-objective combinatorial optimization problem**, extending its possibilities.
- We developed -and are still completing- a dataset of food ingredients enriched with **Life Cycle Assessment (LCA)** data for these three environmental indicators.
- For each ingredient, we quantify:
  - **GHGE:** grams of CO_2 emitted per gram of dish.
  - **Water Consumption:** litres of water used per gram of dish.
  - **Land Usage:** square meters of land per gram of dish.

Considering Sustainability: The Model

The optimization model takes into consideration the following objectives:

$$
\begin{aligned}
\textit{Cost}: \quad & \min_{x_n} \quad c(x_n^{k,d}) = \sum_{d=1}^{D}\sum_{k=1}^{K}\sum_{n=1}^{N} c_n \cdot x_n^{k,d} \\
\textit{Palat}: \quad & \max_{x_n} \quad p(x_n^{k,d}) = sim(M_a, CM) \\
\textit{Sust}: \quad & \min_{x_n} \quad s(x_n^{k,d}) = \sum_{d=1}^{D}\sum_{k=1}^{K}\sum_{n=1}^{N} ghge_n \cdot x_n^{k,d} \\
& \text{s.t.} \quad x_n^{k,d} \in X \\
& \qquad\;\; x_n^{k,d} \;\; binary \;\; \forall\, n, k, d
\end{aligned}
$$

Where:

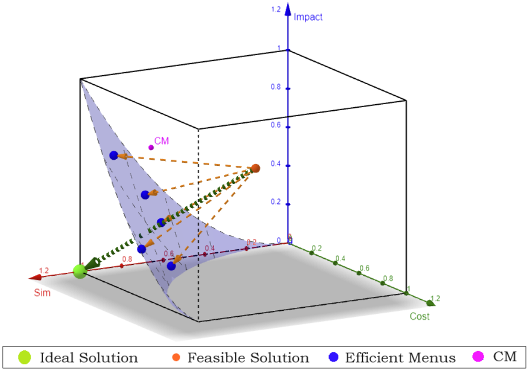
- X is bounded by schedule, labels, nutritional, repetition and MD constraints.
- M_a is the menu formed by variables $x_n^{k,d}$.
- CM is the current menu of a given consumer, to which we try to be similar.

Considering Sustainability.

To consider all the objectives at once **we use an Extended Wierzbicki Achievement Function** (E-WAF) (with different weight vectors w) to explore all the feasible set and reach the Pareto Front in different edges. We optimize this function, with the previous combination of GRASP and Path Relinking algorithms, to generate efficient menus.

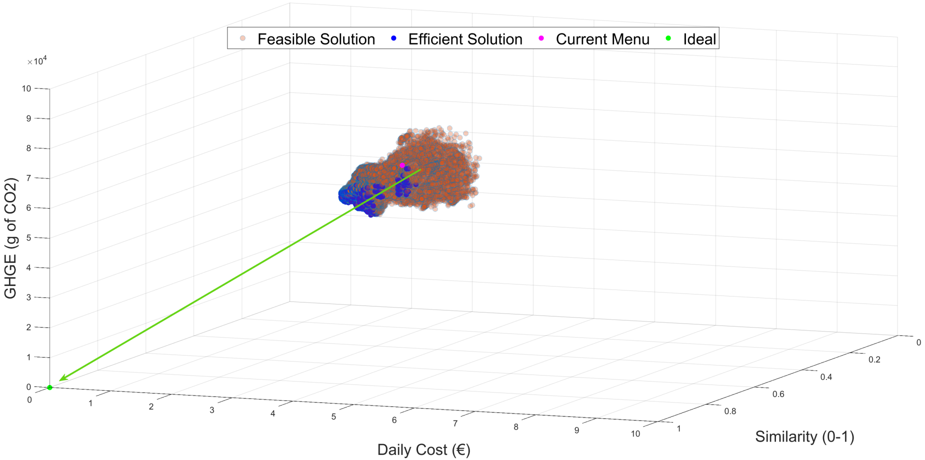
$$\min \Big\{ \max \Big(w_1 \cdot \frac{c(x_j) - c^{ref}}{c^{max} - c^{ref}}, w_2 \cdot \frac{p^{ref} - p(x_j)}{p^{ref} - p^{min}}, w_3 \cdot \frac{s(x_j) - s^{ref}}{s^{max} - s^{ref}} \Big) + \rho \cdot \Big(w_1 \cdot \frac{c(x_j) - c^{ref}}{c^{max} - c^{ref}} + w_2 \cdot \frac{p^{ref} - p(x_j)}{p^{ref} - p^{min}} + w_3 \cdot \frac{s(x_j) - s^{ref}}{s^{max} - s^{ref}} \Big) \Big\} \quad (3)$$

Considering Sustainability.

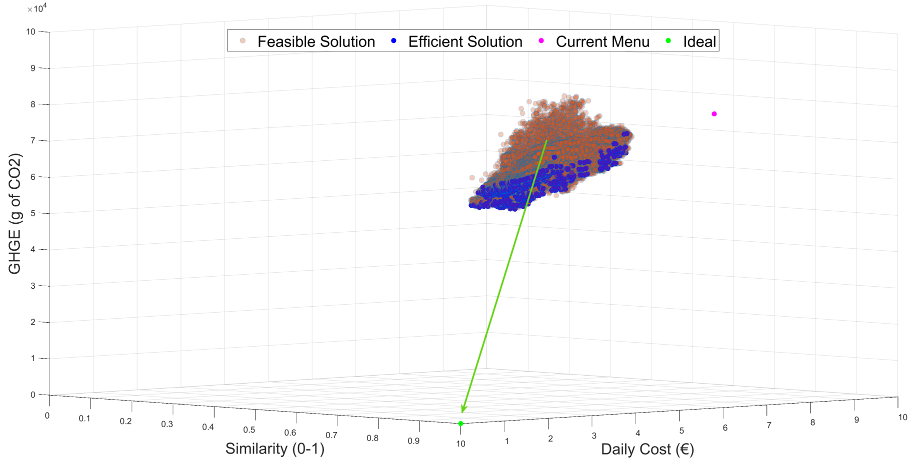


Our aim is taking a feasible solution and improve it using the E-WAF with a random array of weights, **taking the ideal (0,1,0) as the Reference Point** in the E-WAF and reach the Pareto Front with a GRASP inspired algorithm.

Considering Sustainability.



Considering Sustainability.



Considering Sustainability.

We successfully incorporate a sustainability objective, and improve the feasible set to reach new efficient solutions. Our 3D-Objective Space ends up with a dense Pareto Front.

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Solving the Menu Planning Problem: A Multi-Faceted Approach

- **The Problem:**
  - Realistic and culturally-adapted design (Spanish customs, Mediterranean Diet).
  - Successful resolution of complex instances.
- **The SHARP Framework:**
  - **S**ustainability (Objective) – GHGE, water, land use.
  - **H**ealth (Constraints) – Nutritional adequacy.
  - **A**ffordability (Objective) – Economic viability.
  - **R**eliability (Recipes) – Standardized and acceptable meals.
  - **P**alatability (Objective) – Cultural and sensory appeal.
- **Policy and Industry Impact:**
  - Promotes healthier, more sustainable eating patterns.
  - Supports evidence-based food policy and SDG targets (2, 3, 12).
  - Provides insights for the food industry.

What is Next?

- **Enhancing sustainability:**
  - Improve the sustainability perspective.[24]
  - Reduce food waste (grocery planning).
  - Develop and refine SHARP sustainability indicators.
- **Towards real-world implementation:**
  - Develop interactive methods for menu planning.[25]
  - Build a user interface and mobile application.
- **Expanding dietary scope:**
  - Design of acceptable disease-related diets (e.g., diabetes, hypertension).
  - Flexibility to accommodate various lifestyle diets.

[24] Currently working with a team from WUR

[25] Currently working with a team from JYU

This was my Thesis.

Questions? Thank you very much.

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Appendix - Funding

1. PAIDI SEJ 417 - JUNTA DE ANDALUCÍA
2. PID2019-104263RB-C42 - GOBIERNO DE ESPAÑA
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