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A variation of the Diet Problem: Linear Programming used to minimize the carbon footprint of meals provided by a Brazilian company to its employees

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Abstract

The classic Diet Problem aims to minimize the cost of meals while ensuring that they provide the necessary amounts of micro and macro nutrients. This paper presents a variation of the Diet Problem in which the goal is to minimize the carbon footprint of a meal – lunch – provided by a Brazilian company to its employees. The problem of the carbon footprint has been highlighted in recent decades due to its negative effect on the environment, since its accumulation in the atmosphere is largely responsible for the anthropogenic effects of climate change. Thus, efforts aimed at reducing carbon consumption/emission have a very significant cumulative effect towards the maintenance of earth temperature. Three scenarios are proposed for solving the problem, which is done using Linear Programming through the Microsoft Excel Solver software. When comparing the best of the 3 scenarios with the current scenario, it is clear that the application of mathematical modeling to optimize this LPP is extremely advantageous, since it presents a reduction of the carbon footprint by 2.45 times and is much more efficient in meeting nutritional needs. The methodology proposed in this paper can be applied for the most diverse problems of the public, private or military sectors.

Keywords: Diet Problem; Linear Programmimg; carbon footprint; Solver

1. Introduction

The classic problem of diet was proposed by [1], describing the selection of foods for the composition of a diet considered healthy at the time with "low", "moderate" and "high" costs, in order to meet different socioeconomic groups [2]. However, only in later decades, with the advent of computers with superior processing capacity, mathematical methods began to be developed with the aim of minimizing the costs of selection made. As presented

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in [3], the application and results of a food selection algorithm for all meals in institutions that have adopted the optimization system. The author reports a reduction of 10% to 15% in the cost of food in a set of hospitals while meeting the nutritional needs required by the institutions.

With the diffusion of mathematical optimization methods and the popularization of personal computers, several variations of the diet problem were presented, as well as new models for solving these. Many of them are optimized through Linear Programming, but the diversity of problems is great, such as minimizing daily calories for a weight loss diet [4, 5], diet cost optimization for different age groups [6], or minimizing costs with feeding plans to reduce the risk of cancer [7].

However, as observed in [8], a diet that meets basic nutritional needs is not necessarily sustainable in terms of greenhouse gas emissions. Sustainability and carbon footprint are concepts that have been increasingly addressed and are present in various aspects of contemporary life, since the need to reduce the level of carbon in the Earth's atmosphere is immediate and constantly emphasized by scientists [9, 10]. Carbon dioxide is the most important gas when it comes to Earth's heat absorption, and it is needed to make the planet suitable for life. However, excessive amounts of it causes the increase of Earth's temperature beyond a sustainable level, triggering sea level rise, heat waves, greater precipitation and melting ice sheets.

Since the global carbon footprint associated with food – from growing crops through food transportation – is one of the largest in modern era, any means of reducing carbon emissions in the food chain has a great impact toward sustainability. The present work aims to apply a Linear Programming model, through the Solver software of Microsoft Excel, to minimize the carbon footprint associated with a meal – lunch – provided by a Brazilian company to its employees. The model's restriction is to meet the needs of micro and macro nutrients recommended for the Brazilian population.

2. Materials and Methods

Foods of vegetable origin tend to provide low levels of protein and carbohydrates, and higher levels of vitamins at the cost of a relatively low carbon footprint. On the other hand, foods of animal origin tend to be the opposite, containing high levels of protein and fats, but associated with high greenhouse gas emissions. The choice of foods that best make up a diet will always have the counterpart of a possible high carbon footprint; problem that can be solved relatively easily when you have only a few foods available, but the number of combinations grows exponentially with each option we add to the set. Thus, the only way to solve a problem of this complexity in reasonable time is using mathematical optimization models, such as Linear Programming. Mathematical models for decision making in complex problems have been used in several recent problems, such as [11–36].

2.1. Food and carbon emissions

2.1.1. Food and nutritional information

According to information found in [37], foods are classified into groups according to their origins (animal or vegetable) and nutritional similarities, so it is recommended that meals be made composed of foods belonging to various groups, in order to consume the largest variety of micro and macro nutrients. Table 1 shows the grouping used in this work.

A balanced diet should contain several nutrients, so as to keep all systems of the human body functioning closer to optimal. Each food provides a certain amount of nutrients, which should also be consumed in different amounts from each other. The research in [38] shows that nutritional needs may vary according to the region in which they live and the activities that are practiced, and also present a nutritional table with desirable nutritional values for the average Brazilian population. Table 1 also contains the number of shares of each food group that should be present in the meal analyzed.

Associated with the information provided in [4] - table 2 - on the percentage of daily nutrients that each meal should represent, in this work will be used the nutritional values presented in Table 3 as values to be obtained by the optimization model.

Table 1. Food groups and their recommended daily rations

Food Group	Description	Servings per meal
1	Fruits	2
2	Vegetables	2
3	Cereals and seeds	2
4	Fish and Meat	2
5	Milk and dairy products	1
6	Eggs and derivatives	1
7	Industrialized products	1
8	Legumes	1
9	Nuts	1

Table 2. Percentage of micro and macro nutrient intake per meal

Breakfast	Morning snack	Lunch	Afternoon snack	Dinner	Evening snack
20%	5%	35%	5%	30%	5%

Table 3. Amount of micro and macro nutrients recommended for lunch

Nutrient	Cal.	Carb.	Prot.	Vit. A	Vit.B1	Vit. B2	Vit. B3	Vit. C	Lipid	Calcium	Iron	Fibres	Magn.	Sodium	Potassium.
Unit of measure	kcal	g	g	mg	mg	mg	mg	mg	g	mg	mg	g	mg	mg	mg
Recommended daily amount	2000	390	140	2000	3000	3500	50	450	83	1650	26	15	770	2000	4700
Recommended amount at lunch	700	137	49	700	1050	1225	18	158	29	578	9	5	270	700	1645

2.1.2. Carbon footprint

The term carbon footprint refers to the amount of greenhouse gases (converted into units of carbon dioxide – CO2 – according to the amount of effects on the atmosphere) generated along the production chain of each product or service, and this amount varies depending on the stage at which such product or service is in the chain, that is, the closer to the production stage, the lower the carbon footprint; the closer to the final consumer or the disposal of the product, the greater the footprint [39]. In this work will be used values related to the carbon footprint of food while located at the point of sale in order to standardize the data collection.

As stated in [9], the generation of greenhouse gases by agricultural activities represents 19% of the total generated annually and different types, or groups, of foods have carbon footprints that can be found on opposite extremes of a carbon emission spectrum, varying from 60 kgCO2e for 1 kg of beef to 0.4 kgCO2e for 1 kg of apples. Also, as stated in [40], food can account for up to 30% of a household's greenhouse gases emissions.

Recently, [41] compared the food guideline of 7 countries from different continents and identified a considerable discrepancy in associated carbon footprint. According to the authors, for a daily 2000-kcal diet, a US citizen would have a 3.83kgCO2e footprint, whereas an Indian citizen would have a mere 0.86kgCO2e footprint.

It is clear that any contribution to the reduction of the carbon footprint in this sector will have a significant impact on the total emissions of the planet. Data on the carbon footprint of each food used in this study were taken from the https://apps.carboncloud.com/ website, which provides them in kg CO2e/kg – kilogram of carbon dioxide and equivalent per kilogram of food. In problem modeling this unit of measure is converted to kilogram of equivalent-carbon dioxide per serving – kg CO2e/serving.

2.2. Operational Research and Linear Programming

The research in [2] states that Operational Research (OR) is a branch of Mathematics that makes use of the creation of optimization or heuristic models aiming to support and assist decision making [42]. Still according to the author, one of the main models used within the OR is Linear Programming (LP), which consists of the development of linear equations that represent the system to be optimized, including an objective function and the restrictions to be respected.

Linear Programming Problems (LPP) can be represented in general, following the form of the equation system (1) [43]:

$$\begin{aligned} & Max\ Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n \\ & s.t. \\ & a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \leqslant b_1 \\ & a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \leqslant b_2 \\ & \ldots \\ & a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \leqslant b_m \\ & and \\ & x_1 >= 0,\ x_2 >= 0,\ \ldots,\ x_n >= 0 \end{aligned} \tag{1}$$

The authors of [2] and [43] state that the Diet Problem is a classic LPP and therefore LP is used in this work to solve the problem presented. Even the Diet Problem commonly aiming at minimizing the costs associated with a meal or food choice, the application of LP in the solution of the problem under analysis, in which the objective-function is to minimize the carbon footprint, does not alter the characteristics of the problem.

In recent decades, the publication of studies in which LPP involves the minimization of carbon emissions has become more frequent. A review of the literature containing 12 studies with this objective is shown in [44]; a model was developed in [39] to minimize carbon emissions associated with livestock feeding; the authors of [10] modeled a problem similar to the present study, but with the Italian population in mind; and, in [45], under the influence of environmental policies in the United Kingdom, which aim to reduce carbon emissions by up to 80% by 2050, the authors have developed a LP model with this objective.

3. Case study

This work aims to solve the problem identified by a Brazilian company that provides lunch to its employees. Knowing the need to reduce the carbon footprint and how much food production and consumption contributes to the total emissions of the planet, the company, with approximately 500 employees, that is, approximately 500 meals daily, wants to minimize its carbon footprint related to these meals, but at the same time meet the employees' nutritional needs.

As previously reported, the problem is restricted only to the employees' lunch, so the meal should supply at least 35% of the recommended micro and macro nutrients per day (except the number of calories, lipids and sodium, which should be equal to or less than the recommended amount). Other initial restrictions of the problem are: the number of servings of each food group should be equal to that recommended in table 1 (except food group 7 – Industrialized Products, the amount of which must be less than or equal to one serving), and the maximum amount of servings of each food should be equal to 20, forcing Solver to choose a larger variety of foods.

3.1. Mathematical modeling

For the modeling of the proposed problem will be used a list with 57 foods that will have a variable x associated with each of them (x_1, x_2, ..., x_{57}). This variable represents the number of servings of food to be included in the meal. The nutrients to be supplied are the same as those presented in table 3, plus the carbon footprint of each food. The objective function is to minimize the total amount of carbon associated with the meal. The problem was developed in Microsoft Excel and solved with Solver, MS Excel own native tool, which has the ability to solve Linear Programming and Nonlinear Programming problems. The general formatting of the problem in was made in Excel software, while the modeling was done in 3 different scenarios, presented below, and compared with the current scenario.

3.1.1. Scenario 1 – Food group constraints

In this scenario, nutrients constraints - table 3 - and the number of servings per food group - table 1 - were included. The modeling done in Solver is presented below.

1. Min Z = x1*0.023+x2*0.0252+x3*0.0456+…+x56*0.0115+x57*0.0216 where xi is the quantity of serving of food i (i=1 … 57) and the constants are the amount of CO2e footprint associated with the respective food
   Subject to:
2. x1+x9+x30+x33+x35+x36+x37+x38+x55=2 (total servings of Food group 1 must be equal to 2)
3. x2+x3+x10+x11+x15+x19+x22+x23+x24+x40+x48+x52+x53+x56+x57=2 (total servings of Food group 2 must be equal to 2)

4. x4+x5+x7+x12+x13+x14+x20+x21+x27+x34+x39+x44+x45+x49=2 (total servings of Food group 3 must be equal to 2)
5. x6+x16+x17+x18+x46+x47=2 (total servings of Food group 4 must be equal to 2)
6. x29+x31+x32+x50+x51=1 (total servings of Food group 5 must be equal to 1)
7. x41+x42+x43=1 (total servings of Food group 6 must be equal to 1)
8. x27+x54<=1 (total servings of Food group 7 must be less than or equal to 1)
9. x25+x26=1 (total servings of Food group 8 must be equal to 1)
10. x8=1 (total servings of Food group 9 must be equal to 1)
11. xi>=0 (i=1 … 57) (non-negativity constraint)
12. xi<=20 (i=1 … 57) (no more than 20 servings of food i is allowed per meal)
    and 14 equations that represent the nutrient constraints, that follow the form below:
13. $\sum_{i=1}^{57}\sum_{j=1}^{14} xiyj \geq or \leq kj$

Where yj is the amount of nutrient j in a serving of food i and kj is total quantity constraint of nutrient j in the meal served. When solving the problem Solver fills the cells in column B for each food with the recommended quantity of servings and reaches a value of 0.967 kg CO2e/meal, however, in the problem in question it was not possible to find a solution that respects all the number of servings for each food group, nor the recommended amount of some nutrients. Solver returns the warning informing the impossibility of optimal solution.

The constraints not met by Solver were as follows:

- Number of food group 4 - Fish and Meat, which should be 2, but the model returns 0.078
- Number of feed group 6 - Eggs and derivatives, which should be 1, but the model returns 0
- Number of feed group sections 9 – Nuts, which should be 1, but the model returns 0
- Minimum amounts of Protein and Vitamins B3

3.1.2. Scenario 2 - Modeling for unconstrained food groups

Since the model in the previous scenario did not return a solution that met all the constraints imposed, and since the constraints associated with the number of recommended servings for each food group are only intended to ensure that all nutrients are consumed in their recommended amounts, these constraints were removed in scenario 2. On the other hand, the constraints associated with the minimum amount of nutrients to be ingested will be maintained, without negatively affecting this aspect of the diet. Thus, the equations will be similar to the ones presented in section 3.1.1., excluding constraints 2 through 9. The objective function found was 1.99 kg CO2e/meal, however, once again Solver did not find a viable solution to the problem, since one of the constraints was not met. Namely: Minimum amount of Protein.

3.1.3. Scenario 2 - Modeling of unconstrained food groups and relaxation of the maximum amount of calories constraint

Although the result presented in the previous scenario was closer to meeting all the constraints imposed, the restriction referring to the maximum recommended number of calories for the meal under analysis has already dyed its limit and makes it impossible to choose different foods or in different quantities, meaning not all other constraints can be respected. To achieve the recommended amount for all other nutrients, the calorie constraint had its value changed to the minimum necessary in order to meet all other constraints. In this scenario, the number of calories should be less than or equal to 742 kcal, compared to the recommended 700 kcal. It is believed that, by representing only 2.1% of the total daily calories, the surplus of 42 kcal can be easily compensated in the other meals of the day, which represent 70% of the daily intake of nutrients. As an answer to the modeling of this scenario, Solver found the optimal solution of 1,779 kg CO2e/meal and met all constraints.

3.1.4. Example of a meal currently served

By way of comparison with the scenarios proposed above, this section presents the values for a usual meal offered by the company. The carbon footprint is equal to 4.34 kg CO2e/meal and several nutritional constraints are not met. Namely:

1. Maximum amount of calories
2. Minimum amount of vitamin A, vitamin B2 and calcium

3.2. Results Analysis

In this section the results of all scenarios are grouped together along with the comparison with the values of the current real scenario in order to quantify the gains and benefits of the optimization model. For comparison purposes, table 4 contains the number of servings of each food in the current scenario and scenarios 3.

Table 4. Foods chosen in each scenario and their carbon footprint

Food	Current	Scenario 3
Pineapple	1.00	5.71
Pumpkin	0.00	11.76
Lettuce	1.00	0.00
Wholegrain Rice	1.50	0.00
Tuna	0.00	0.38
Banana	1.00	0.00
White potato	1.00	0.00
Lean beef	1.00	0.00
Steamed cabbage	0.00	9.20
Black bean	1.50	0.00
Orange	1.00	0.00
Pasta	0.50	0.00
Boiled chicken egg	1.00	0.00
Portuguese bun	1.00	0.00
Grilled fish	0.00	1.35
Ripe tomato	1.00	0.43
kg CO_2e/meal	4,34	1,77

Table 5 shows the amounts of nutrients provided in each scenario and a measure of how far from the recommended measure each scenario is. This measure is the absolute percentage deviation for each nutrient individually, and the mean absolute percentage deviation for each scenario in general.

For nutrients that do not meet daily recommendations, the absolute percentage deviation is the absolute difference between the recommended value and the quantity provided by the meal, divided by the recommended amount. The mean absolute percentage deviation is the sum of the absolute percentage deviations divided by the amount of nutrients that did not reach the recommended amount.

Table 5. Total nutrients in each scenario and their deviations from the recommended values

		Current		Scenario 1		Scenario 2		Scenario 3	
Nutrient	Recommendation	Quantity	Deviation	Quantity	Deviation	Quantity	Deviation	Quantity	Deviation
Kcal	700	1827.3	161.0%	700.0		700.0		742.0	6.0%
Carb.	137	325.8		137.0		137.0		137.0	
Protein	49	90.3		28.2	42.5%	36.4	26.0%	49.0	
Vit. A	700	429.7	38.6%	1281.5		5066.6		4044.2	
Vit. B1	1050	1761.9		1335.8		1174.6		1351.1	
Vit. B2	1225	1027.7	16.1%	2220.8		2272.5		2274.9	
Vit. B3	18	23.3		11.3	37.1%	18.0		18.0	
Vit. C	158	161.2		520.1		636.4		600.3	
Lipids	29	19.6		6.0		8.2		5.8	
Calcium	578	387.4	33.0%	837.3		1592.3		1410.8	
Iron	9	14.5		23.8		17.0		16.9	
Fibres	5	8.9		9.5		5.5		5.0	
Magnesium	270	274.7		270.0		270.0		270.0	
Sodium	700	699.8		265.5		73.8		280.8	
Potassium	1645	2368.9		4180.5		4704.3		4158.9	
MAPD			**62.2%**		**39.8%**		**26.0%**		**6.0%**

From the analyzed scenarios, Scenario 3 presents the lowest mean deviation compared to the recommended nutritional values for the meal. This was also the second-best result in relation to the total carbon footprint, second only to Scenario 1 – but this presents the worst average deviation among the modeled scenarios.

Scenario 3 modeling returned a total carbon footprint of only 1.77 kg CO2e and an average deviation from the recommended amount of nutrients of only 6% for the extra 42 calories so that all other nutrients had their constraints met. On the other hand, a standard meal has a carbon footprint of 4.34 kg CO2e – 2.45 times more than that obtained in Scenario 3 – and an average deviation of 62.2% – the worst result of all scenarios.

Considering the average of 500 meals provided daily, the company would have a daily carbon footprint of 885 kg CO2e compared with the current 2170 kg CO2e. This difference of 1285 kg CO2e, according to the online tool created by the United States Environmental Protection Agency - on https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator - is equivalent to the consumption of approximately 510 litres of gasoline.

4. Conclusion

The application of Linear Programming models for system optimization is an already consolidated practice and used in various situations and industries with different objectives. In recent decades, with a strong focus on carbon emissions reduction, it would be inevitable that such models would also be used in scenarios with this need.

The present work, which analyzed a variation of the Diet Problem – a classic application of Linear Programming – whose objective was to minimize the carbon footprint of a meal – lunch – provided by a Brazilian company to its employees, while meeting the daily nutritional recommendations.

Although the modeling of the most favorable scenario exceeded the number of calories – however, by only 42 kcal – all constraints related to the other nutrients were met, in addition to generating a combination of food servings with a carbon footprint of only 1.77 kg CO2e, value 2.45 times lower than a standard meal currently provided. Thus, one can consider the mathematical modeling developed for this LPP a success.

As exposed previously, the flexibility of Linear Programming models makes them suitable to be applied to different scenarios and businesses, thus the strategy presented in this study can be replicated by different companies and be expected to generate similar results when accounting for individual restrictions and constraints.

References

1. Stigler, G.J.: The cost of subsistence. Journal of farm economics. 27, 303–314 (1945)
2. Winston, W.L., Goldberg, J.B.: Operations research: applications and algorithms. Thomson Brooks/Cole Belmont (2004)
3. Balintfy, J.L.: A mathematical programming system for food management applications. Interfaces. 6, 13–31 (1975)
4. Kripka, R.M.L., Peccati, C.: UMA VARIAÇÃO PARA O PROBLEMA CLÁSSICO DA DIETA: A MINIMIZAÇÃO DO CONSUMO DE CALORIAS. Revista CIATEC-UPF. 6, (2014)
5. Khoshaim, A.B.: A Linear Programming Optimization Model For A Diet Program. Review of Business and Finance Studies. 12, 31–39 (2021)
6. Sultana, J., Hasan, M.M., Tanni, S.I., Ruman, U., Islam, S.: An Approach to Diet Cost Optimization for Different Age Groups Using Linear Programming. Open Access Library Journal. 9, 1–11 (2022)
7. Alaini, R., Rajikan, R., Elias, S.M.: Diet optimization using linear programming to develop low cost cancer prevention food plan for selected adults in Kuala Lumpur, Malaysia. BMC public health. 19, 1–8 (2019)
8. Macdiarmid, J.I.: Is a healthy diet an environmentally sustainable diet? Proceedings of the Nutrition Society. 72, 13–20 (2013)
9. Gates, B.: How to avoid a climate disaster: the solutions we have and the breakthroughs we need. Knopf (2021)
10. Ferrari, M., Benvenuti, L., Rossi, L., De Santis, A., Sette, S., Martone, D., Piccinelli, R., Le Donne, C., Leclercq, C., Turrini, A.: Could dietary goals and climate change mitigation be achieved through optimized diet? The experience of modeling the national food consumption data in Italy. Frontiers in nutrition. 7, 48 (2020)
11. Costa, I.P. de A., Moreira, M.Â.L., Costa, A.P. de A., Teixeira, L.F.H. de S. de B., Gomes, C.F.S., Santos, M. Dos: Strategic Study for Managing the Portfolio of IT Courses Offered by a Corporate Training Company: An Approach in the Light of the ELECTRE-MOr Multicriteria Hybrid Method. International Journal of Information Technology & Decision Making. 1–29 (2021). https://doi.org/10.1142/S0219622021500565
12. Drumond, P., Basílio, M.P., Costa, I.P. de A., Pereira, D.A. de M., Gomes, C.F.S., dos Santos, M.: Multicriteria Analysis in Additive Manufacturing: An ELECTRE-MOr Based Approach. Presented at the October 29 (2021)
13. de Almeida, I.D.P., de Araújo Costa, I.P., de Araújo Costa, A.P., de Pina Corriça, J.V., Lellis Moreira, M.Â., Simões Gomes, C.F., dos Santos, M.: A multicriteria decision-making approach to classify military bases for the Brazilian Navy. Procedia Computer Science. 199, 79–86 (2022). https://doi.org/10.1016/j.procs.2022.01.198
14. Moreira, M.Â.L., Gomes, C.F.S., Santos, M., Basilio, M.P., Costa, I.P. de A., Rocha Junior, C. de S., Jardim, R.R.-A.J.: Evaluation of drones for public security: a multicriteria approach by the PROMETHEE-SAPEVO-M1 systematic. Procedia Computer Science. 199, 125–133 (2022). https://doi.org/10.1016/j.procs.2022.01.016
15. Nassim Mellem, P.M., de Araújo Costa, I.P., de Araújo Costa, A.P., Lellis Moreira, M.Â., Simões Gomes, C.F., dos Santos, M., de Pina Corriça, J.V.: Prospective scenarios applied in course portfolio management: An approach in light of the Momentum and ELECTRE-MOr methods. Procedia Computer Science. 199, 48–55 (2022). https://doi.org/10.1016/j.procs.2022.01.007
16. Santos, N., Rocha Junior, C. de S., Moreira, M.Â.L., Santos, M., Gomes, C.F.S., Costa, I.P. de A.: Strategy Analysis for project portfolio evaluation in a technology consulting company by the hybrid method THOR. Procedia Computer Science. 199, 134–141 (2022). https://doi.org/10.1016/j.procs.2022.01.017
17. do Nascimento Maêda, S.M., de Arajo Costa, I.P., Simões Gomes, C.F., dos Santos, M., da Mota, I.S., de Barros Teixeira, L.F.H. de S.: Economic and edaphoclimatic evaluation of Brazilian regions for African mahogany planting - an approach using the SAPEVO-M-NC

ordinal method. Procedia Computer Science. 199, 323–330 (2022). https://doi.org/10.1016/j.procs.2022.01.196
18. Rocha Junior, C. de S., Moreira, M.Â.L., Santos, M.: Selection of interns for startups: an approach based on the AHP-TOPSIS-2N method and the 3DM computational platform. Procedia Computer Science. 199, 984–991 (2022). https://doi.org/10.1016/j.procs.2022.01.124
19. Tenorio, F.M., Santos, M. Dos, Gomes, C.F.S., Araujo, J.D.C., De Almeida, G.P.: THOR 2 Method: An Efficient Instrument in Situations Where There Is Uncertainty or Lack of Data. IEEE Access. 9, 161794–161805 (2021). https://doi.org/10.1109/ACCESS.2021.3132864
20. Pereira, D.A.D.M., Santos, M. Dos, Pinheiro De Araujo Costa, I., Angelo Lellis Moreira, M., Terra, A.V., Junior, C.D.S.R., Simoes Gomes, C.F.: Multicriteria and Statistical Approach to Support the Outranking Analysis of the OECD Countries. IEEE Access. 10, 69714–69726 (2022). https://doi.org/10.1109/ACCESS.2022.3187001
21. Moreira, M.Â.L., Gomes, C.F.S., Pereira, M.T., dos Santos, M.: SAPEVO-H2 a Multi-criteria Approach Based on Hierarchical Network: Analysis of Aircraft Systems for Brazilian Navy. Presented at the (2023)
22. dos Santos, F.B., dos Santos, M.: Choice of armored vehicles on wheels for the Brazilian Marine Corps using PrOPPAGA. Procedia Computer Science. 199, 301–308 (2022). https://doi.org/10.1016/j.procs.2022.01.037
23. Costa, I.P. de A., Basílio, M.P., Maêda, S.M. do N., Rodrigues, M.V.G., Moreira, M.Â.L., Gomes, C.F.S., dos Santos, M.: Algorithm Selection for Machine Learning Classification: An Application of the MELCHIOR Multicriteria Method. Frontiers in Artificial Intelligence and Applications. 341, 154–161 (2021). https://doi.org/10.3233/FAIA210243
24. Jardim, R., dos Santos, M., Neto, E., Muradas, F.M., Santiago, B., Moreira, M.: Design of a framework of military defense system for governance of geoinformation. Procedia Computer Science. 199, 174–181 (2022). https://doi.org/10.1016/j.procs.2022.01.022
25. Costa, I.P. de A., Maêda, S.M. do N., Teixeira, L.F.H. de S. de B., Gomes, C.F.S., Santos, M. dos: Choosing a hospital assistance ship to fight the covid-19 pandemic. Revista de Saúde Pública. 54, 79 (2020)
26. Moreira, M.Â., Costa, I.P., Pereira, M.T., dos Santos, M., Gomes, C.F., Muradas, F.M.: PROMETHEE-SAPEVO-M1 a Hybrid Approach Based on Ordinal and Cardinal Inputs: Multi-Criteria Evaluation of Helicopters to Support Brazilian Navy Operations, (2021)
27. Tenório, F.M., dos Santos, M., Gomes, C.F.S., Araujo, J. de C.: Navy Warship Selection and Multicriteria Analysis: The THOR Method Supporting Decision Making. In: Springer Proceedings in Mathematics & Statistics, vol 337. pp. 27–39. Springer, Cham (2020)
28. Gomes, C.F.S., Santos, M. dos, Teixeira, L.F.H. de S. de B., Sanseverino, A.M., Barcelos, M.: SAPEVO-M a group multicriteria ordinal ranking method. Pesquisa Operacional. 40, 1–20 (2020)
29. Jardim, R.R.J., Santos, M., Neto, E., da Silva, E., de Barros, F.: Integration of the waterfall model with ISO/IEC/IEEE 29148:2018 for the development of military defense system. IEEE Latin America Transactions. 18, 2096–2103 (2020). https://doi.org/10.1109/TLA.2020.9400437
30. Costa, I.P. de A., Costa, A.P. de A., Sanseverino, A.M., Gomes, C.F.S., Santos, M. dos: BIBLIOMETRIC STUDIES ON MULTI-CRITERIA DECISION ANALYSIS (MCDA) METHODS APPLIED IN MILITARY PROBLEMS. Pesquisa Operacional. 42, (2022). https://doi.org/10.1590/0101-7438.2022.042.00249414
31. Costa, I.P. de A., Basílio, M.P., Maêda, S.M. do N., Rodrigues, M.V.G., Moreira, M.Â.L., Gomes, C.F.S., Santos, M.: Bibliometric Studies on Multi-Criteria Decision Analysis (MCDA) Applied in Personnel Selection. Frontiers in Artificial Intelligence and Applications. 341, (2021). https://doi.org/10.3233/faia210239
32. Maêda, S.M. do N., Basílio, M.P., Costa, I.P. de A., Moreira, M.Â.L., dos Santos, M., Gomes, C.F.S.: The SAPEVO-M-NC Method. Frontiers in Artificial Intelligence and Applications. 341, 89–95 (2021). https://doi.org/10.3233/faia210235
33. Maêda, S.M. do N., Basílio, M.P., Costa, I.P. de A., Moreira, M.Â.L., dos Santos, M., Gomes, C.F.S., de Almeida, I.D.P., Costa, A.P. de A.: Investments in Times of Pandemics: An Approach by the SAPEVO-M-NC Method. Presented at the October 29 (2021)
34. Gomes, C.F.S., Rodrigues, M.V.G., Costa, I.P. de A., dos Santos, M.: Ordering of Warships for the Brazilian Navy Using the New Method: AHP-Gaussian with Pearson's Correlation. Presented at the October 29 (2021)
35. Drumond, P., de Araújo Costa, I.P., Lellis Moreira, M.Â., dos Santos, M., Simões Gomes, C.F., do Nascimento Maêda, S.M.: Strategy study to prioritize marketing criteria: an approach in the light of the DEMATEL method. Procedia Computer Science. 199, 448–455 (2022). https://doi.org/10.1016/j.procs.2022.01.054
36. Barbosa de Paula, N.O., de Araújo Costa, I.P., Drumond, P., Lellis Moreira, M.Â., Simões Gomes, C.F., dos Santos, M., do Nascimento Maêda, S.M.: Strategic support for the distribution of vaccines against Covid-19 to Brazilian remote areas: A multicriteria approach in the light of the ELECTRE-MOr method. Procedia Computer Science. 199, 40–47 (2022).
37. UNICAMP: Tabela brasileira de composição de alimentos/ NEPA – UNICAMP
38. Padovani, R.M., Amaya-Farfán, J., Colugnati, F.A.B., Domene, S.M.Á.: Dietary reference intakes: aplicabilidade das tabelas em estudos nutricionais. Revista de Nutrição. 19, 741–760 (2006)
39. Moraes, L.E., Wilen, J.E., Robinson, P.H., Fadel, J.G.: A linear programming model to optimize diets in environmental policy scenarios. Journal of dairy science. 95, 1267–1282 (2012)
40. Jones, C.M., Kammen, D.M.: Quantifying carbon footprint reduction opportunities for US households and communities. Environmental science & technology. 45, 4088–4095 (2011)
41. Kovacs, B., Miller, L., Heller, M.C., Rose, D.: The carbon footprint of dietary guidelines around the world: a seven country modeling study. Nutrition journal. 20, 1–10 (2021)
42. Basílio, M.P., Pereira, V., Costa, H.G., Santos, M., Ghosh, A.: A Systematic Review of the Applications of Multi-Criteria Decision Aid Methods (1977–2022). Electronics. 11, 1720 (2022)
43. Frederick Hillier, Lieberman, G.: Introduction to Operations Research. McGraw-Hill Education, New York (2020)
44. Van Dooren, C.: A review of the use of linear programming to optimize diets, nutritiously, economically and environmentally. Frontiers in nutrition. 5, 48 (2018)
45. Green, R., Milner, J., Dangour, A.D., Haines, A., Chalabi, Z., Markandya, A., Spadaro, J., Wilkinson, P.: The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change. Climatic Change. 129, 253–265 (2015)