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Daily food planning for families under Covid-19: combining Analytic Hierarchy Processes and Linear Optimisation

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ABSTRACT
In many households, preparation of food in normal times proves to be problematic, particularly when parents endeavour to keep their children on a balanced diet. The COVID-19 pandemic has further exacerbated this problem imposing the requirement of social distancing, which led to disruptions in the food supply chain and multiplication of responsibilities faced by families with children. The present study revisits the standard "Diet Problem" to address these challenges and to develop a participatory approach to provide a diversified weekly meal plan that is easy and fun but simultaneously complies with the unique requirements of each participant. This is done by providing a novel framework, which combines linear optimisation with the Parsimonious Analytic Hierarchy Process, a method for individual choices. This novel approach to participatory modelling is tested within two young family settings in Brazil. The model produced through this contemporary framework provides a weekly menu that best meets expectations of the members of a young family in the context of the COVID-19 pandemic.

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COVID-19 pandemic; diet problem; linear optimisation; Analytic Hierarchy process; parsimonious preference information; multicriteria decision analysis; lockdown

1. Introduction

At the time of writing this Paper [mid-January 2021] the Coronavirus Disease 2019 (COVID-19) has infected more than 97 million people worldwide causing 2.1 million deaths (Johns Hopkins, 2021). The pandemic rudely disordered all areas of the society. Lives have been disrupted by uncertainty and continuous lockdown in almost all parts of the world.

The outbreak of the coronavirus pandemic and the associated social distancing measures imposed by governments in many countries (Gruère & Brooks, 2021) inevitably transformed the usual routine of families, including the aspects pertaining to food planning and preparation. This has been done in a three-fold manner. First, usual social support available to families with children has been discontinued (Gadermann et al., 2021). The existing formal (e.g., school, childcare, after-school clubs) and informal (e.g., grandparents, relatives or close friends) support systems for families were interrupted significantly increasing the pressure faced by working parents. Indeed, following the World Health Organisation's (WHO) guidance on social distancing, businesses, schools and educational institutions became closed, forcing parents to manage a significant number of additional responsibilities associated with their children staying at home (Nicola et al., 2020). This, in turn, had a knock-on effect on family food planning and preparation that, at normal times, requires careful consideration of numerous constraints. With social isolation in place, this process intensified as further constraints had to be considered. These additional constraints imposed by disruptions in the food supply chains across the world, including in China and the USA (Dou et al., 2020; Semba et al., 2020), materialised in unavailability of various products. These implications of COVID-19 underline the rationale for the present study, which aims to account for the "new reality" in designing a diverse meal plan for a young family of four in the time of the pandemic.

To explore an optimal way of planning an appropriate and health-conscious diet during the COVID-19 lockdown period, this study revisits the standard *diet problem* formulation, which is a well-known example of an application of the constrained linear optimisation procedure (Stigler, 1945). Specifically, the model invokes the confinement conditions as well as food preferences and requirements of all family members in the decision-making process. Methodologically, these additional constraints are explicitly accounted for by proposing a participatory framework, which combines both, the original and parsimonious versions of the *Analytic Hierarchy Process (AHP)* method, with integer linear optimisation modelling, to generate a simple participatory decision approach to facilitate the planning of a healthy weekly meal schedule.

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Specifically, the study aims to answer the following research questions (RQ):

RQ1: What are the main variables to consider by a young family when planning their meal preparation in the context of the current pandemic?

RQ2: Can a combination of a participatory method for individual choices, such as Analytic Hierarchy Process, and linear optimisation, generate a model that facilitates planning a weekly diet for working parents in times of the pandemic?

RQ3: Can the technique of Parsimonious Analytic Hierarchy Process (PAHP) be used as a strategy to enhance and facilitate the participative process especially with non-expert evaluators?

Providing an answer to these questions enables us to contribute to the existing literature in a two-fold manner. First, we add to the existing debate in Operations Research (OR) and Management Science by introducing a multi-methodological participatory approach to planning a healthy and palatable diet, where a couple of systemic methodologies are utilised in conjunction. In particular, the model that we propose combines a multi-criteria decision approach (AHP) – a participatory method for individual choices – which ensures that the consumption preferences of individual family members are accounted for, with linear optimisation modelling. We choose this approach to encourage the participation of all family members, even children, so that their subjective preferences regarding various food alternatives can be objectively captured and evaluated. Indeed, the participatory element makes the decision-making process legitimate and increases its chance of success in practice (Eden & Sims, 1981). When applying the AHP tool, we also integrate the parsimonious preference information for the cases of big dimensions matrix. This is an additional contribution to the literature, where the debate involving the practical cases of parsimonious preferences is limited.

Our second contribution is to the literature focusing on the impact that the COVID-19 pandemic has had on food planning. Specifically, we test the proposed theoretical contribution using the particular case of two Brazilian families consisting of working parents with young children attending primary school, and we report our results in this study. By engaging the family members in the decision-making process, we provide scarce evidence to the field of OR regarding participatory modelling in food planning practices in times of lockdown. This is important, since the ability to plan and implement a healthy diet given the new conditions is crucial to ensure families' good physical and emotional health. Indeed, it has been documented that the lockdown and social isolation simultaneously increase the risk of obesity and weaken the resistance to the on-going pandemic (Jackson-Morris et al., 2020). As the proposed model can be adapted to other contexts and scenarios, our contribution is to provide families with the practical and easy to implement tool to support their health in this challenging period of social isolation, working from home and school closure (Coller & Webber, 2020).

The rest of this article is organised as follows. Section 2 revisits the diet problem and its most current applications, including relevant studies in the context of the COVID-19 pandemic. This section highlights the study's rationale and helps to position its contribution. Section 3 outlines the methodology including the process of structuring the problem, the participatory approach framework and the model proposed to address the research questions. In Section 4, the results of the implementation of the decision-making procedure and its sensibility analysis are presented. Section 5 provides relevant discussion, while Section 6 concludes highlighting further areas of applications of the proposed model.

2. Relevant literature

2.1. *The classical "Diet Problem"*

The *Diet Problem* is a classical application of *linear programming* in OR and it has been one of the first optimisation problems studied back in the 1930s and 1940s (Stigler, 1945). Since then, the problem and the corresponding quantitative technique have been widely utilised to produce other diet solutions in a long history of the applications (van Dooren, 2018) by designing individual diets (Maillot et al., 2010) as well as population diets (J. H. Kim et al., 2019; Rajikan et al., 2017).

It has been recognised however, that linear approximation of the objective function for diet formulation alone is not sufficient when individual preferences and consumption habits are invoked. Indeed, Fletcher et al. (1994) show that the application of linear programming to diet choices results in undesired unpalatable solutions, supporting an early argument by Frisch, who calls for palatable as well as nutritional meal plans (Sandmo, 1993). Consequently, the approach leads to diet outcomes that meet nutrient requirements under the constraint of a budget but forsake pleasure derived from their consumption. The palatability issue has been subsequently addressed by Smith (1959) and since, other constraints, including environmental sustainability, have been successfully incorporated into the model (Arnoult et al., 2010; Tyszler et al., 2016; van Dooren et al., 2015). However, the recent pandemic created a further need for revisiting the Diet Problem.

2.2. The impact of the COVID-19 pandemic on food planning and preparation

The impact of the recent pandemic for different domains of family life has been widely acknowledged in the literature (see, e.g., Power, 2020), including its significance for a daily diet. Indeed, Jayawardena and Misra (2020) recognise that diet became a major "casualty" of the pandemic with notable implications for food habits in different parts of the world. For instance, one of the implications suggested by Coll (2020) and Duarte (2020) is a reduced consumption of healthy food leading to inferior health outcomes. Research by Muscogiuri et al. (2020), Song et al. (2020), and the Brazilian Ministry of Health (Schneiders, 2020) confirms these undesirable effects by pointing to a significant increase in the instances of sleep disorders, consumption of alcohol (Ingram et al., 2020), smoking, chronic diseases (Martinez-Ferran et al., 2020), as well as a higher risk of cardiovascular diseases and eating disorders, including obesity (Calcaterra et al., 2020). These findings are further supported by Di Renzo et al. (2020) and Batlle-Bayer et al. (2020), who document raising irregularities in the eating habits of individuals in Italy and Spain during the period of self-isolation. Notwithstanding, unhealthy eating habits during the pandemic led to further impairments surrounding mental health issues such as poorer psychological wellbeing (López-Bueno et al., 2020) and increased stress (Ingram et al., 2020), thus, highlighting the importance of a healthy diet during lockdown.

While dietary intake and the associated nutrition have widespread implications on physical and mental health of individuals, optimal nutrition in itself is a valuable resource that transcends the individual (Jackson-Morris et al., 2020; Ma & Lee, 2012). This calls for wider promotion of a healthy diet as part of the efforts to strengthen immunity during the pandemic. This is particularly relevant in the context of the most vulnerable people who, apart from the pandemic, are affected by unemployment and difficulties in accessing healthy eating (Mehta, 2020) or are deprived of their routines and activities in a phase of physical and cognitive development (Calcaterra et al., 2020). The latter argument imposed more responsibility on parents of small children creating significant organisational and time management challenges for young families (Auðardóttir & Rúdólfsdóttir, 2021). Suddenly, with the pandemic, even the most established routine had to be re-arranged demanding parents to carefully balance the wide array of their responsibilities (Gadermann et al., 2021; Vescovi et al., 2021). This was caused by the interruption of formal and informal support networks, in particular schools and nurseries, which played a pivotal role in supporting a healthy routine of children, thus the entire families, prior to the pandemic.

Along with the increased family pressure, the pandemic caused interruptions in the food supply chains. The reports from Brazil and worldwide identify high prices and food shortages as consequences of those disruptions. These factors exacerbate the complexity associated with food planning during the COVID-19 pandemic. In fact, Jovančević and Milićević (2020), highlight food shortage as the household members' primary concern during this period. This has been further confirmed by Dou et al. (2020) and Semba et al. (2020) who argue that even developed countries like China and the USA suffered from issues related to food insecurity and shortages during the pandemic. This generates a whole new set of factors to consider for families concerned with their diet.

2.3. Participatory approach to food planning under COVID-19 constraints

Recently Joanis (2020) has revisited the diet problem illustrating a hypothetical case of a US family in the context of some of the aforementioned challenges induced by the pandemic. In particular, he demonstrates how to feed a family effectively during a pandemic using the linear programming (LP) method, thus, minimising family food costs subject to nutritional constraints, food availability, palatability of food combinations, and meal variation. In addition, he restricts the number of monthly food shopping trips to one.

The present study takes a novel multi-methodological approach to the diet problem during lockdown, which enhances the solution to the LP optimisation problem by introducing a participatory modelling tool. Specifically, we combine the original and parsimonious Analytical Hierarchy Process (AHP and PAHP) with the linear programming problem in designing the optimal diet plan.

The participatory multi-criteria tool (AHP) developed and further refined by Saaty (2000, 1980) is an approach for organising and analysing complex decisions. By quantifying its criteria and possible solutions (referred to as alternatives), this method provides a framework for a decision needed to solve the complex problem. The AHP process has been extensively analysed by Emrouznejad and Marra (2017), who reviewed 8,441 articles published between 1979 and 2017 on AHP. Some good examples of AHP application can be found in Abuabara et al. (2019), K. Kim et al. (2015), Abebe et al. (2013), and Mathiyazhagan et al. (2014). In this study, the AHP method is combined with the linear optimisation to ensure that the resulting diet plan encompasses individual family members' preferences through considering the unique confinement conditions.

Indeed, the combination of linear programming with the original or parsimonious version of the AHP tool leads to the comprehensive approach resulting in several advantages over alternative multi-criteria methodologies (Singh & Dubey, 2017). One of them is the fact that the AHP tool not only enables to simultaneously capture subjective and objectives aspects of the decision-maker's choice in a quantifiable manner but also permits the participation of non-experts, such as children, by invoking simple pairwise comparisons. In addition, AHP features cyclicality, which enables to evaluate the consistency of assessments made by the decision makers by checking procedure and rank reversal in case of inconsistencies (Duleba, 2020).

The selection of the AHP tool is further supported by the relevant participatory framework, which, by engaging families in the research process, largely resembles the facilitated modelling approach in OR (Franco & Montibeller, 2010). The latter technique for stakeholders' involvement was employed to lay down a clear pathway to support the development of the family members' decision-making (Franco & Rouwette, 2011). Specifically, this approach benefits from (i) *full participation* through the encouragement to voice opinions and ideas, (ii) *mutual understanding* of individual needs that leads to a sustainable and legitimate agreement, (iii) *inclusive solutions* by integrating everybody's perspectives and needs, and (iv) *shared responsibility* as all suggestions are endorsed by the members (Kaner, 2007). Consequently, the proposed participatory approach advocated in this study helps determine the best diet plan for families subjected to the lockdown restriction as part of a successful and participative decision-making process.

2.4. The study's contribution

In practical terms, the participatory framework that we propose enables to produce an exact diet plan involving meals and snacks for all family members throughout the day. The present model not only focuses on costs minimisation, but it also accounts for family members' preferences and tastes. The latter is important for two reasons. First, it highlights how our approach facilitates bringing family members together and strengthening interpersonal relationships (Gadermann et al., 2021; Laguna et al., 2020; Palumbo et al., 2019; Tuchlinski, 2020) in the context of food planning and preparation. Second, we support the idea of the "food being a form of medicine", in line with the recent Independent Review commissioned in the UK, to assess the quality of food in NHS hospitals, who suggested that it is possible to serve "delicious and nutritious" meals on a budget (Report of the Independent Review of NHS Hospital Food, 2020, p. 8). Indeed, better decision-making in the context of the diet problem invokes not only the constraints of budget and calories intake (Parlesak et al., 2016), but also the palatability reflected in individual preferences for different tastes and their variety (Maillot et al., 2010). This is subject to food availability; hence, we also include the mentioned food scarcity constraints in the model. Additionally, successful implementation of these solutions in health care requires participatory methodologies (Holm et al., 2013; Witteman & Stahl, 2013). Thus, while this study offers a non-clinical approach, it invokes a multi-disciplinary planning (Leeftink et al., 2020; Lodi et al., 2016) and preventive application in health care.

Finally, the current project not only proposes an initial guide for a participative approach, but it also provides a rationale for a greater involvement of policy makers in promoting healthy eating practices in families and beyond. Our findings suggest that the proposed participative approach delivers not only a ready-made weekly menu that satisfies individual preferences of family members, but it also contributes to the enhancement of the relationships between family members, resulting, among other things, in greater family union and happiness. This is relevant in the context of a sustainable dietary pattern adoption (Springmann et al., 2021) particularly during the pandemic, where increasingly family members struggle to cope with their physical and mental health (Gadermann et al., 2021). Thus, the exercise promoted in this article is a stimulus for the discussion of government measures, emergency or temporary, direct or indirect to support families with working parents in these difficult times.

3. Research design and methodology

Food planning in times of pandemic is particularly complex in that there is a large number of variables to be considered when the goal is to provide both, healthy and tasty meals, given the stay-at-home requirement. This situation mirrors hard and soft complexity which can be characterised as a "mess" (Ackoff, 1981) or "wicked" problem in that it "evades a definitive formulation" (Churchman, 1987; Rittel & Webber, 1973).

To acknowledge this complexity, we started by surveying the problem at hand, which was followed by structuring the problematic situation to recognise the existing patterns of relationships between the variables. Specifically, we employed some of the concepts relevant to a messy problem proposed by Checkland (1981, 1999) by drawing a Rich Picture (RP) that contains elements pertaining to the information, variables, people, institutions and relationships of the problematic situation provoked by the pandemic. Indeed, RP techniques have been used extensively in systems studies, particularly as a first step to make sense of a messy situation. The UK Open University has developed a good repository of advice as to the use of this technique: UK Open University: The art of Rich Pictures https://www.open.edu/openlearn/science-maths-technology/engineering-technology/the-art-rich-pictures.

Employing this simple technique, we then built the rich image with all the identified elements. Specifically, via an iterative exercise conducted through various Google Meets sessions involving the project team members, we were able to interpret the complex situation concerning the confinement of a young family and provide a corresponding RP. Figure 1 shows the final version of the RP based on experience of one of the two families (Family I). The picture was drawn and enhanced at Procreate App by one of the family members. The RP corresponding to Family II is available upon request, but not included here to avoid making the article overly lengthy.

Figure 1 illustrates two possible scenarios confronted by the family. On the left, a “chaotic” situation triggered by the pandemic is depicted. It involves emotional burden and parental stress arising due to an overload of responsibilities. This leads to a general “disorder” in which “good” habits have been forgotten and replaced by eating permissibly, overusing electronics, and so on. On the right-hand side, the picture shows a more harmonious situation that emerges as a result of the involvement and collaboration of all family members in daily activities, such as studying, working, cooking, socialising, eating, playing etc. However, the confinement imposing the permanent co-presence of family members in a limited physical space generates continuous pressure in the household. To ease down the pressure and to create a plan ensuring all family members’ satisfaction and enjoyment, we explicitly focused our research on the diet planning. The RP was built and shared with all four members of the family, to place the emphasis on the role that the interaction and the participatory nature of food planning play in coping with stress. Indeed, conversations and participatory interaction involving the whole family were seen as key to improve the situation. Without those conversations, stress and chaos would continue to increase.

To complete this section, we now describe the four main sequential activities that form the remain of the methodological framework. These are presented in Figure 2.

The ***first activity*** involves a series of family meetings, which are labelled “*workshops”*. We suggest a set of three workshops with some defined tasks, which we present next. However, duration and number of meetings could be adapted case by case.

- *First workshop*: This meeting aims to introduce the subject and the process to all invited participants. Subsequently, some questions are posed to participants to initiate an open discussion focusing on planning an appropriate diet during the lockdown. Some of the proposed questions include: “*In terms of food*, what would please *each of the participants?*”; “*Which special requests would the participants have?*”; ‘*What would be important during the lockdown period?* It is important at this stage of the project development to talk openly about the meaning of feeding during the quarantine period. The expected

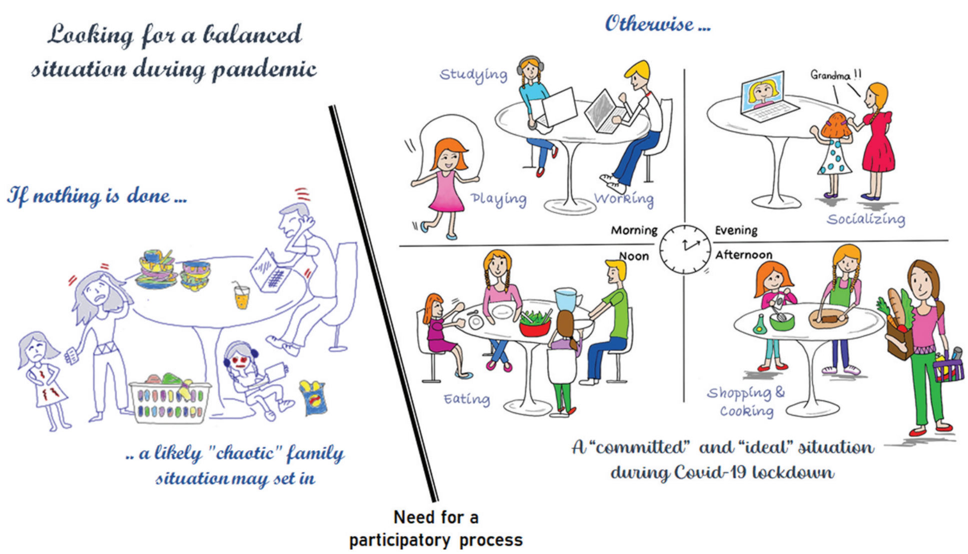

Figure 1. A Rich Picture illustrating a participatory approach to cope with the stress in a young family during the COVID-19 confinement.

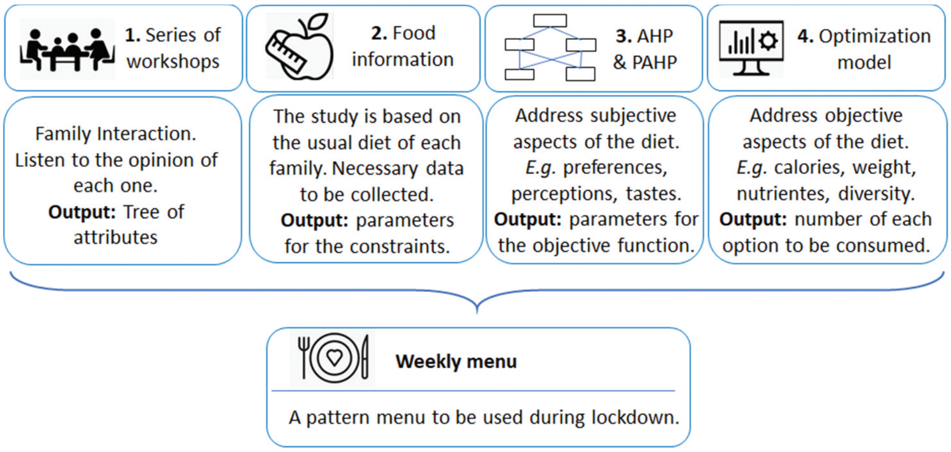

Figure 2. Methodological framework.

outcome of this initial workshop is to determine a tree of values and attributes which are specific to each family unit and, that would be considered in the next steps.

- *Second workshop*: A draft containing a list of meal options designed using the information obtained in the first workshop is presented to the family members for a discussion and validation. The objective here is to agree upon a limited number of possible and workable daily meal alternatives among the participants. The meals to be considered shall reflect the consumption habits of each family unit. We suggest considering breakfast, lunch, morning/afternoon snack, dinner, supper, and brunch- whatever is the case.
- *Third workshop*: A defined list of validated alternatives for each meal is elaborated using the insights from the previous workshops. It is individually presented to each family member in order to elicit his/her perception. These subjective parameters emerge through a pairwise comparison process. Here, we suggest an individual approach to be adopted (instead of a group approach) as a family unit (living in the same home) tends to be small (involving between two to six people). This provides fairer opportunity to respect and accommodate everyone's opinion. However, using a group approach is also permitted.

The result from the third workshop provides the data necessary for the multi-criteria decision analysis tool, the *Analytic Hierarchy Process* (AHP) reinforced by the *Parsimonious Analytic Hierarchy Process* (PAHP). This is applied as the ***second activity*** of the methodology proposed.

AHP is technique structured to organise and analyse decisions by means of a hierarchical structure. The present study adopted some particularities which prove the flexibility and utility of this technique. These focused firstly on ranking the alternatives that have been previously established as reasonable and agreed by family members. At the *criteria* level (below *objective* in the AHP model), one can say that diary meals are not sensible comparable criteria once all the meals are served on a particular the day. However, one must consider that there are some matutine or evening people who can appreciate one or another meal in the day. Hence, it is also reasonable to treat *criteria* as a way of categorisation. Additionally, not all alternatives are valid for all meals (as it is suggested in a standard *alternative-criteria* comparison process in AHP), but it is more appropriate and helpful in our particular case. All these considerations are embedded in the model and can be verified in Figure 3. The Consistency Ratio (CR) that measures the consistency ratio of the judgements made is based on the eigenvector method from the pairwise comparisons and respected the threshold of 0.1.

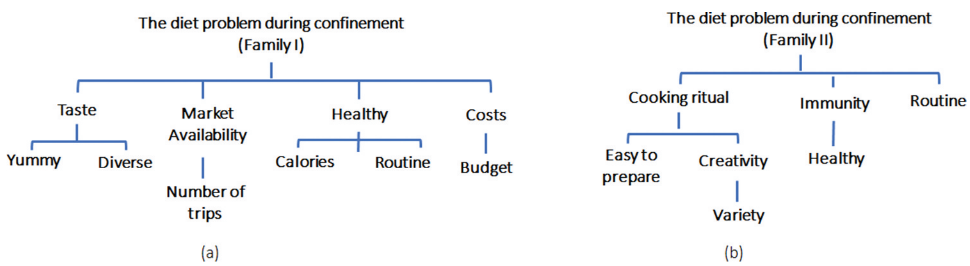

Figure 3. Tree of values and attributes of Family I (a) and Family II (b) raised during the first workshop.

The second tool particularity used in our application is the new Parsimonious AHP (PAHP). This novel technique was recently introduced by Abastante et al. (2019) and there are still very few applications reported (Abastante et al., 2018; Duleba, 2020). We believe that this technique will become prominent in the future and the present study contributes to its consolidation by testing it in the current framework. The main idea of PAHP is to unburden the evaluator, the latter generally understood as non-experts or, in our cases, children, by reducing the number of pairwise comparisons (if compared to original AHP) that they are exposed to. This is done by integrating a prominent concept of *reference points* in case of many pairwise comparisons occurring when a large number of alternatives is available. This enables us to simplify the problem at hand and make the questionnaire more understandable to the evaluator. Moreover, this approach reduces cognitive effort of the decision maker and avoid the issue of rank reversal which may cause confusion in case of many alternatives involved.

In the present exercise, we adopted PAHP in matrix greater than 9×9. To have a basic idea of this reduction consider the case of 10 alternatives, $n = 10$, for a specific criterion. This leads to $C_2^n = \binom{n}{2} = \binom{10}{2} = 45$ pairwise comparisons. The number of reference points suggested here is $n' = 4$ (see, Table 1 in Abastante et al., 2019 for other sizes), so the 10×10 large pairwise comparison matrix would be replaced by a 4×4 matrix producing $C_2^4 = \binom{4}{2} = 6$ pairwise comparisons instead. This is about 13% of the effort needed compared with the case when reductions are not implemented. Following on from the application of classical AHP on the small subset of reference evaluations, the remaining alternatives (not part of the reference points), which initially received a rating of alternatives (0 to 100) by the evaluator, will be calculated by interpolation, and then normalised. Subsequently, this will generate the priority vector which will feed the global score.

Table 1. Individual global ranking for family I (left) and for family II (right).

Family I						*Family II*					
Alternative	Member #1	Member #2	Member #3	Member #4	Total (w_i)	Alternative	Member #1	Member #2	Member #3	Member #4	Total (w_i')
B1	0.063	0.023	0.011	0.058	0.155	B1	0.066	0.005	0.040	0.036	0.147
B2	0.021	0.065	0.005	0.027	0.119	B2	0.027	0.008	0.096	0.077	0.208
B3	0.148	0.255	0.029	0.034	0.465	B3	0.012	0.043	0.009	0.007	0.072
B4	0.278	0.191	0.074	0.196	0.739	B4	0.037	0.053	0.033	0.026	0.150
L1	0.007	0.005	0.012	0.027	0.052	B5	0.025	0.032	0.023	0.024	0.104
L2	0.005	0.002	0.009	0.007	0.024	S1	0.007	0.018	0.008	0.011	0.044
L3	0.047	0.007	0.010	0.005	0.069	S2	0.006	0.018	0.005	0.006	0.035
L4	0.012	0.016	0.013	0.002	0.043	S3	0.006	0.008	0.006	0.016	0.036
L5	0.026	0.031	0.017	0.019	0.093	S4	0.003	0.003	0.001	0.002	0.010
S1	0.066	0.015	0.154	0.058	0.292	S5	0.002	0.002	0.004	0.002	0.010
S2	0.011	0.029	0.078	0.201	0.318	S6	0.001	0.001	0.001	0.001	0.005
S3	0.033	0.059	0.027	0.022	0.141	S7	0.001	0.001	0.004	0.003	0.010
S4	0.129	0.169	0.400	0.232	0.930	S8	0.001	0.001	0.001	0.006	0.009
D1	0.020	0.007	0.007	0.005	0.039	S9	0.001	0.008	0.006	0.002	0.018
D2	0.006	0.015	0.017	0.028	0.066	S10	0.001	0.008	0.008	0.006	0.023
D3	0.017	0.005	0.004	0.022	0.047	S11	0.001	0.003	0.005	0.006	0.015
D4	0.026	0.003	0.017	0.003	0.049	S12	0.001	0.007	0.003	0.008	0.019
Y1	0.061	0.032	0.038	0.007	0.137	L1	0.061	0.083	0.071	0.026	0.241
Y2	0.018	0.046	0.064	0.015	0.142	L2	0.011	0.033	0.023	0.013	0.080
Y3	0.004	0.026	0.016	0.033	0.079	L3	0.069	0.083	0.071	0.038	0.261
	1.000	**1.000**	**1.000**	**1.000**	**4.000**	L4	0.045	0.033	0.078	0.044	0.199
						L5	0.029	0.037	0.078	0.095	0.239
						L6	0.018	0.083	0.071	0.044	0.216
						L7	0.029	0.018	0.010	0.038	0.095
						L8	0.018	0.018	0.078	0.095	0.209
						T1	0.029	0.083	0.071	0.044	0.227
						T2	0.018	0.033	0.010	0.038	0.099
						D1	0.023	0.008	0.024	0.031	0.086
						D2	0.144	0.128	0.031	0.067	0.370
						D3	0.055	0.020	0.015	0.024	0.113
						D4	0.055	0.015	0.005	0.009	0.084
						D5	0.144	0.066	0.079	0.128	0.417
						E1	0.023	0.017	0.012	0.010	0.062
						E2	0.007	0.007	0.010	0.009	0.032
						E3	0.005	0.001	0.001	0.001	0.009
						E4	0.003	0.004	0.002	0.001	0.009
						E5	0.003	0.002	0.001	0.001	0.006
						E6	0.009	0.002	0.003	0.003	0.017
						E7	0.007	0.002	0.004	0.003	0.016
							1.000	**1.000**	**1.000**	**1.000**	**4.000**

4.1.1. Mathematical modelling

The ***third activity*** is the search for quantitative data and information that will be used in the linear programming model to make it consistent and realistic. Thus, the information to be raised will depend on what was defined in the previous activities. As the main issue is food planning, we suppose that the information of interest shall be related to the amount of nutrients (e.g.,: vitamins, minerals), energy sources (e.g.,: calories, carbohydrates, fats, proteins), groups (fruits, vegetables, meats, grains, milk products), portion sizes, costs, perishability and whatever is required in each specific case.

In the ***fourth activity***, an integer linear optimisation model is formulated and implemented in accordance with the findings from the preceding stages. This leads to each family having its own optimisation model. In these models, the *decision variables* are to be determined. The objective is to maximise a linear function. The constraints are requirements (equalities or inequalities) of the decision context and are associated with some linear combination of the decision variables (Vanderbei, 2014).

4. Mathematical modelling and model implementation

This section discusses the model implementation in each of the activities of the methodological framework presented in the previous section. We implemented the proposed framework in two different families: (i) one of the authors made her family available for testing the model; and (ii) a family friend that was invited to participate in the proposed research together with his own family, happily accepted. We start by describing the families and the conditions of lockdown in the time of the research. Subsequently, we present the main outcomes of each *workshop*. We then introduce and discuss the linear optimisation model and the corresponding results.

4.1. Participatory phase

Families description and lockdown conditions: Both families consist of four members composed by a professional couple (mother and father aged between 38 and 43) and two children, age 8 and 12, and 9 year-old twins, respectively. Due to social distancing, all kids have been taking online classes, eating at home every day and being involved in some activities such as setting table, assisting meal preparation and washing dishes. In *family I*, due to quarantine, the mother works full time from home. She used to prepare the meals at home 2–3 times a week and counts on snacks on the busiest days. The father works remotely full time with some exceptions when required to make engineering tests in a laboratory. Before quarantine, he used to have lunch near to his workplace. Prior to the pandemic, children used to have lunch at home, sometimes in the school canteen and other times taking a healthy snack. Delivered ("ready to eat") meals used to be an option during the weekends. Physical activities were drastically reduced at that time, and the family had to dispense of the regular swimming exercise they undertook prior to lockdown. In ***family II***, the mother worked various shifts at a paediatric hospital. She ate her meals in the hospital canteen and stuck to this same routine during the quarantine period. The father started to work remotely and took over the responsibility of daily cooking (before the quarantine, he used to have lunch near his workplace). Twins used to have lunch in the school canteen. This family initially stocked food but realised it was unnecessary. For this family, food delivery was not a usual alternative. They frequently served up for dinner what was cooked for lunch. The couple noted an increase in their consumption of wine and in order to incentivise the twins towards more activities they bought bicycles. None of the members of either of the family reported dietary restrictions due to allergies or coeliac disease, for instance, nor for ideological reasons such as veganism or related to religious reasons.

For ***family I***, the ***first workshop*** took place a week after the lockdown begins. The meeting was based on a discussion with all family members who were excited and keen about participating in the project. The father started the discussion- claiming that he had an initial feeling of being on holiday, when working remotely from home. This mode of working is a new requirement suddenly mandated by his employer and required by all employees. However, he is not really prepared for working from home. At first, he feels free to eat junk food and having snacks more frequently because of the new working mode. Apart from this practice not being good for his health and wellbeing in the long term, it also not a good example for children. Indeed, the oldest child is concerned with gaining weight and suggested having dessert removed during the quarantine period. The youngest child wanted to have delicious meals every day (which is a subjective argument that AHP accommodates). In addition, the family believed they should reduce the number of visits to the grocery store, while maintaining the level of fresh food. They understood that although food supply is not a problem, the grocery stores were limiting the number of shoppers who are allowed to shop at any one time. Additionally, once in the shop, the family wanted to select the products as quickly as possible to minimise the risk of exposure to the virus.

For ***family II***, the father (who acted as the facilitator) conducted this ***first workshop***. One of the twins indicated which meals she liked to eat by listing traditional Brazilian rice and beans, meat, pasta, and tomato sauce, and she emphasised the need for "real food". In contrast, her sister indicated her preference for candies, fruits, and apple juice. She thought it was important to drink more water than usual. It was her understanding that a healthy diet would protect them from the COVID-19. The mother also recognised that healthy food could help to maintain good immunity. Therefore, she tried to avoid ultra-processed food. The father started to consume more coffee than usual. He considered the ritual of cooking important and relaxing. However, he started offering repeat menu alternatives during the week in his aim to have enough time to dedicate to his work. He admitted his own struggle with creativity in cooking. His food preferences were fruit compote, milk candy, and dark chocolate. He also started to prepare pizza and cakes at home. Overall, he found that this reflection on diet/meals was interesting and valuable. The family had no restrictions about going to the supermarket and went as many times as was necessary. The mothers of both families (unnecessarily) worried about stocking up food at the beginning of the lockdown. These productive conversations in the first workshop finished with a number of values and attributes illustrated in Figure 4. The tree diagrams were shared (by the author-facilitator and father-facilitator) and validated together to each family before the beginning of the second workshop.

In the time between the first and the ***second workshop***, a list outlining a variety of meals was prepared based on the family's pre-lockdown routine of cooking at home. In ***family I***, after the discussion, adjustment and validation, a list of four (4) alternatives for breakfast (B), five (5) alternatives for lunch (L), four (4) alternatives for the afternoon snack (S), four (4) alternatives for dinner (D), and three (3) alternatives for delivery meals (Y) was drawn up. Some alternatives were made available as part of one or two meals (for instance, certain *deliveries* for lunch or dinner, and certain snack options for breakfast are offered). In ***family II***, the final list comprised: five (5) alternatives for breakfast (B); twelve (12) alternatives for snack (S) (consumed before lunch and in the afternoon); eight (8) alternatives for lunch (L) (which could be also consumed for dinner); two (2) alternatives for take-away food (T) that is taken for lunch; five (5) alternatives for dinner (D); and seven (7) alternatives for dessert (E) (consumed after lunch and after dinner). Detailed information of alternative meals (including description and parameters) is presented in Tables A1 and A2 of the Appendix A.

For ***family I*** case, the attributes "*diversified*", "*number of exits*", "*calories*", "*routine*" and "*budget*" were considered as restrictions of the problem. The most subjective one, which is the designation of the meal's taste as "*yummy*", is part of the objective function. Within the AHP method, being "*yummy*" is the goal. Similarly, for ***family II*** case, the attributes "*variety*", "*ease to prepare*", *and* "*routine*" were considered as constraints of the problem. The most subjective one, which is the designation of the meal as being sufficiently "*healthy*" as to contribute to the immunity, is part of the objective function. Within the AHP method, being "*healthy*" is the goal. In both cases, meals were entered as criteria, and the meal options served as alternatives. Figure 3 illustrates the corresponding AHP model for each case. Meal options (alternatives) were assessed during the third workshop in the AHP process.

During the ***third workshop***, the original AHP process was applied to each family member in each family. It was explained to each participant how the weights were assigned indicating by verbal judgement the preferred alternative. In ***family I***, one shall choose one of the compared criteria for breakfast, lunch, snack and dinner in light of the objective (*yummy*) and, the alternative meals in light of the criteria (each daily meal). This process elicited individual opinions surrounding the *yummy* attribute.

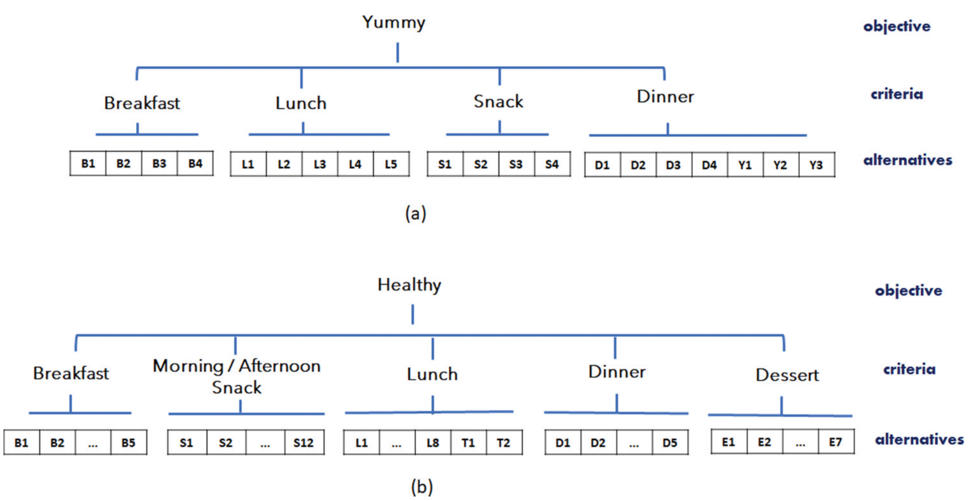

Figure 4. Decision Tree of AHP Model for Family I (a) and Family II (b).

Pairwise judgements were made by assigning a value between 1 and 9, the *nine-point scale* (Saaty, 1990). This was with value 1 designating indifference among the options and 9 designating strong preference (*"my favourite dish!"*). Representing the weight vector for the *yummy* attribute was the parameter used for the decision variables in the objective function.

In case of ***family II***, one of the authors of the paper conducted the workshop via Google Meets and by exchanging quick messages in case of any doubt. As before, the author explained to each participant how the importance is assigned, so that each participant chose one of the compared criteria for: breakfast, a snack (including morning and afternoon), lunch, dinner and dessert in light of the objective (*healthy*), and the alternative meals in light of the criteria (each daily meal). This process elicited individuals' opinions in relation to the *healthy* attribute. Pairwise judgements were made by assigning a value between 1 and 9, with value 1 designating indifference among the options (*both are equally healthy!*) and 9 designating a strong feeling of a healthy meal (*"really good for my immunity!")*. In this case, we adopted the parsimonious preference information through PAHP for two of the criteria: (i) *snack*, which included 12 alternatives; and (ii) *lunch*, which included 10 alternatives to be evaluated. In case of the first criterion, it would result in $C_2^n = \binom{n}{2} = \binom{12}{2} = 66$ pairwise compar isons due to the large *12 × 12* matrix. In case of the second criterion, it would result in $C_2^{10} = \binom{10}{2} = 45$ pairwise comparisons to be completed due to the large *10 × 10* matrix. In both cases, by adopting PAHP, we used 4 references points, and the evaluation of preferences was reduced to a *4 × 4* matrix, implying in only $C_2^4 = \binom{4}{2} = 6$ pairwise comparisons. The suggestion to use it came from one of the reviewers of the article. The use of reference points followed on from the original AHP evaluation with fewer alternatives, and the subsequent use of interpolation made the decision process faster and simpler to apply. Specifically, any necessary rank reversal was easier to understand by the evaluator and it was clear to identify when any inconsistency happened. All participants fully understood that the PAHP was a good strategy to our case. In particular, the non-expert evaluators could identify their inconsistencies in making judgements which also aided the communication with facilitator. In the end, the participatory process proved to be more satisfactory for the parties, and a feeling of more reliable results emerged. The priority vector generated in the process fed the remaining original AHP global score. The information in Table 1 summarises the global ranking emerging from responses of each member and their sum for both family cases. This information fed the linear programming model as representing the weight vector for the *yummy* and *healthy* attribute, respectively, both parameters used for the decision variables in the objective function of each model.

Whilst simple and classical, the mathematical modelling through linear programming of the diet problem is customised in this study to each family case as shown in Figure 5 and Figure 6, respectively. The time horizon of the project covered only a weekly planning of meals (a seven-day period). The intention was to replicate the weekly pattern diet during the lockdown just by replacing similar dishes such as: cornmeal mush by couscous, cookies by cake.

Parameters

$i = \{1, ..., R\}$:	set of alternatives;
$j = \{1, ..., N\}$:	set of meals;
w_i:	preference (AHP result) assigned to alternative *i*;
p_i:	weight (in kg) of alternative *i*;
c_i:	calories of alternative *i*;
b_i:	estimated cost of alternative *i*;
P:	weekly total load of shopping (in kg);
C:	recommended weekly calories intake for the family;
B:	available weekly budget;
M_j	number of meal *j* served weekly;
L_M	number of alternative *i* (homemade) repeated weekly;
L_D	number of alternative *i* (delivery) repeated weekly.

Decision variables

x_{ij}: number of alternatives *i* served weekly as part of meal *j*.

Objective function

Maximize $$\sum_{j=1}^{N}\sum_{i=1}^{R} w_i \cdot x_{ij}\,. \qquad (1)$$

Subject to:

$$\sum_{i=1}^{R}\sum_{j=1}^{N} p_i \cdot x_{ij} \le P, \qquad i = 1,\dots,R \quad j = 1,\dots,N \qquad (2)$$

$$\sum_{i=1}^{R}\sum_{j=1}^{N} c_i \cdot x_{ij} \le C, \qquad i = 1,\dots,R \quad j = 1,\dots,N \qquad (3)$$

$$\sum_{i=1}^{R} x_{ij} = M_j, \qquad j = 1,\dots,N \qquad (4)$$

$$\sum_{i=1}^{R}\sum_{j=1}^{N} b_i \cdot x_{ij} \le B \qquad i = 1,\dots,R \quad j = 1,\dots,N \qquad (5)$$

$$\sum_{j=1}^{N} x_{ij} \le L_M\,, \qquad i = 1,\dots,17 \qquad (6)$$

$$\sum_{j=1}^{N} x_{ij} \le L_D\,, \qquad i = 18,\dots,20 \qquad (7)$$

$$x_{ij} \ge 0 \;\; and \;\; x_{ij} \in \mathbb{Z} \qquad (8)$$

$$i \in \{1, ..., R\} \;\; and \;\; j \in \{1, ..., N\}. \qquad (9)$$

Figure 5. Mathematical modelling for family I case.

Parameters

$i = \{1, \ldots, R'\}$: set of alternatives;
$j = \{1, \ldots, N'\}$: set of meals;
w_i' preference (AHP result) assigned to alternative i;
e_i: ease of preparation index attributed of alternative i;
E: level of difficulty of preparation of the dishes served within a week;
M_j times meal j is served during the week;
L_M' number of alternatives i (homemade) repeated weekly;
L_T number of alternatives i (take-away) repeated weekly.

Decision variables

x_{ij}: number of alternatives i served in the week as part of meal j.

Objective function

$$\text{Maximize} \quad \sum_{j=1}^{N}\sum_{i=1}^{R} w_i' \cdot x_{ij} \,. \qquad (10)$$

Subject to:

$$\sum_{i=1}^{R'}\sum_{j=1}^{N'} e_i \cdot x_{ij} \le E, \qquad i = 1, \ldots, R' \quad j = 1, \ldots, N' \qquad (11)$$

$$\sum_{i=1}^{R'} x_{ij} = M_j, \qquad j = 1, \ldots, N' \qquad (12)$$

$$\sum_{j=1}^{N'} x_{ij} \le L_M', \qquad i = 1, \ldots, 39 \ (less\ 25{,}26) \qquad (13)$$

$$\sum_{j=1}^{N'} x_{ij} \le L_T, \qquad i = 25, 26 \qquad (14)$$

$$x_{ij} \ge 0 \quad and \quad x_{ij} \in \mathbb{Z} \qquad (15)$$

$$i \in \{1, \ldots, R'\} \quad and \quad j \in \{1, \ldots, N'\}. \qquad (16)$$

Figure 6. Mathematical modelling for family II case.

A selection of seasonal fruits, kinds of pasta, and sauces also helped to maintain a greater variety. Next, we describe the constraints of the models for each case.

In ***family I*** case, the goal was to maximise family satisfaction in relation to the *yummy* attribute. Thus, the objective function (1) is represented by the sum of the importance attributed to each alternative *i;* multiplied by the amount of each alternative *i;* served weekly in meal; *j*

The other attributes were considered as the model's constraints and are detailed below:

- ***Weight of shopping bags***: this constraint (2) had two features: (i) *firstly*, food shopping in the family's neighbourhood was prioritised. Beyond strengthening local economy, going to a supermarket or a grocery shop at least provided a family member an opportunity to include outdoor movement in the daily routine; (ii) *secondly*; the weight of the neighbour's shopping basket had to be taken into consideration. The limit for the total weight of the basket was 45 kg per week. This weight corresponded to three shopping trips, each one with 15 kg of purchased goods. We allocated 10 kg to purchases for the neighbour. Cleaning and personal hygiene products were not considered in this shopping routine.

A neighbour aged over 60 who was part of the high-risk group and could not go out even for shopping was given weekly (sometimes daily but with weekly checking or in accordance with other shopping plans) support for grocery pick up. The amount the family spent on her shopping was fully refunded, so it did not affect the family's budget. However, the extra weight in the shopping bags is accounted for. This voluntary assistance has been quite common during the pandemic period- not only supporting neighbours but also elderly relatives and friends. Additionally, there has been outreach and support to more needy families, through food parcels donations.

- ***Daily calories intake***: calories are an important metabolic indicator to be controlled with attention to intake of: carbohydrates, fats, protein, minerals, and vitamins. The model used integrated calorie content with the sensory signal of taste (Jacobs & Sharma, 1969). Generally, an ideal intake of calories varies depending on age, metabolism, and levels of physical activity, amongst other things. In order to establish a limit for the family's calories intake, we used professional indices for children; (BCM[1],n.d.) and adults; (BCM[2],n.d.), supplied by the *Baylor College of Medicine*. These indices were adjusted according to: sex (female/male), body weight (kg), height (cm), age (years), and activity profile (low/moderate/intense). The latter was considered low for all family members due to the quarantine measures. The results were: 1,903 kcal intake for member #1; 2,519 kcal for member #2; 2,147 kcal for member #3; and 1,728 for member #4. The entire family's calories intake was 8,297 per day, and 58,079 per week.
- ***Routine***: the routine was kept by serving all four meals every day at a convenient time to the family and it was according to constraint (4). The timetable was not included in the model, however, the number of meals served for each meal (breakfast, lunch, snack and dinner) weekly amounted to 7 (=M_j). Some meals were interchanged with an option for a delivery order for lunch.
- ***Budget***: the food budget was limited to BRL 600 per week (=B), as captured by inequality (5). The proposed budget was considered a reasonable figure according to household budget survey performed by the Brazilian Institute of Geography and Statistics (IBGE, 2019). This amount did not include expenses for cleaning and personal hygiene supplies, and shopping for the neighbour.

- ***Variety***: restrictions (6) and (7) were made meaningful by limiting the number of repetitions of certain options during the week. By repeating an option, one might save time cooking a larger amount at once. However, frequent repetitions were not desirable, since on some days, family members had to be practical in going about whatever planned activities. Therefore, it was proposed that the delivery orders should be limited to one (L_D) per week for each option whilst the other options to three (L_M) times a week.

And finally,

- ***Domain of variables***: constraint (8) defines the domains of decision variables to be non-negative and integers. Additionally, as given in (9), the model included 20 options (R = 20) and 4 daily meals (N = 4), which related to breakfast, lunch, snack and dinner, respectively.

In case of ***family II***, the goal was to maximise family satisfaction in relation to the *healthy* attribute. Thus, the objective function (10) is represented by the sum of the importance attributed to each alternative i, multiplied by the amount of each alternative i served weekly as part of meal j. The other attributes are considered as the model's constraints and are detailed below:

- ***Ease of preparation***: constraint (11) refers to the individual ability of the cook (the father) to prepare a certain meal. For this, he attributed a level from 1 to 4 to each meal, with level 1 indicating meals that are very simple to prepare. For instance, these involved preparation through defrosting. Level 2 corresponds to meals with less than 1-hour of cooking time, while level 3 indicates a medium consumption time of the meals, which can result from producing a large number of dishes and cookware for washing. Finally, level 4 describes laborious meals that require initial preparing. Examples of those are homemade pizza or a codfish dish. The difficulty level attributed in the case of level 2 is 98 (= 7 days x 7 meals x 2-index).
- ***Routine***: it was kept going by serving all seven meals every day at a convenient time to the family given by constraint (12). The timetable is not included in the model, however, the number of meals served weekly for each meal (breakfast, morning and afternoon snacks, lunch, dinner, and desserts) totalled 7 (=M_j) for each meal.
- ***Variety***: restrictions (13) and (14) were made meaningful by limiting the number of repetitions of certain options during the week. As the father is the person in charge of cooking, working and taking care of children, he needed to save time by cooking larger amounts that could be served more than once. Thus, it was proposed to limit the take-away orders to one (L_T) per week for each option, whilst the other options were two (L'_M) times a week.

Finally,

- ***Domain of variables***: constraint (15) defines the domains of decision variables as non-negative and integers. Additionally, as given in (16), the model included 39 options ($R' = 39$) with 7 daily dishes served, which corresponded to 5 meals ($N' = 5$): breakfast, snack, lunch, dinner, and a dessert, respectively.

To keep the article as concise as possible, we have omitted additional data of the models, such the judgements provided by each participant. However, this information is available upon request.

4.1.2. Results and sensibility analysis

In this section, we present the results and analysis for ***family I*** case followed by ***family II*** case. Both models were implemented using Microsoft Excel (for AHP and parsimonious AHP in the second case) and PuLP library from Python (for linear optimisation). Table 2 presents the results obtained for the original model and for some additional simulations resulting from the calculation of the *shadow prices* of the weight, calories, and price resources. These are explained in more detail below.

Analysing *weight* shows that the increase of one unit (i.e., 1 kg) on the right-hand side of inequality (2), enhanced the objective function by 0.006/kg (shadow price of the weight resource). This led to consideration of an extra weight, due to increasing the number of exits either by going to the supermarket by car or by including a purchase within a home delivery. The first two alternatives increased the exposure to the virus and contamination risks, while the third one actually became the norm. In the simulation of the original model, an additional exit was included, thus, increasing the weight from 35 kg (load destined to the family, excluding neighbour's load) to 50 kg weekly (simulation 1 in Table 2).

(i) For *calories intake* (inequality (3), the shadow price was null; meaning a non-active restriction (slack > 0). In this circumstance, an exception made for more sweets (for example), would not increase the value of the objective function and, therefore, the family's satisfaction. Moreover, this situation contributed to undesirable extra weight.

Table 2. Results and simulations (Family I).

	Option (*i*)	Model	Original	Simulation 1 (Weight = 50 kg)	Simulation 2 (Budget = BRL650)	Simulation 3 (50 kg + BRL650)
Breakfast	B1(1)	x_{11}	1	1	1	1
	B2(2)	x_{21}	0	0	0	0
	B3(3)	x_{31}	3	3	3	3
	B4(4)	x_{41}	3	3	3	3
	S3(12)	x_{121}	0	0	0	0
Lunch	L1(5)	x_{52}	0	0	0	0
	L2(6)	x_{62}	0	0	0	0
	L3(7)	x_{72}	2	1	2	2
	L4(8)	x_{82}	3	3	3	3
	L5(9)	x_{92}	0	0	0	0
	D2(15)	x_{152}	0	2	0	0
	D3(16)	x_{162}	2	1	2	2
	D4(17)	x_{172}	0	0	0	0
	Y2(19)	x_{192}	0	0	0	0
	Y3(20)	x_{202}	0	0	0	0
AfternoonSnack	B1(1)	x_{13}	0	0	0	0
	B2(2)	x_{23}	0	0	0	0
	B3(3)	x_{33}	0	0	0	0
	B4(4)	x_{43}	0	0	0	0
	S1(10)	x_{103}	1	1	1	1
	S2(11)	x_{113}	3	3	3	3
	S3(12)	x_{123}	0	0	0	0
	S4(13)	x_{133}	3	3	3	3
Dinner	L1(5)	x_{54}	0	0	0	0
	L2(6)	x_{64}	0	0	0	0
	L5(9)	x_{94}	3	3	3	3
	D1(14)	x_{144}	0	0	0	0
	D2(15)	x_{154}	0	0	0	0
	D3(16)	x_{164}	1	2	1	1
	D4(17)	x_{174}	1	0	0	0
	Y1(18)	x_{184}	1	1	1	1
	Y2(19)	x_{194}	0	0	1	1
	Y3(20)	x_{204}	1	1	1	1
Objective Function			**8,755**	**8,769**	**8,848**	**8,848**

(ii) The *budgetary* constraint in inequality (5) was an active constraint and could have improved the value of the objective function if more resources were allocated to food shopping. The shadow price of this resource was 0.002/BRL. In the simulation of the original model, we included an additional budget of 50 BRL per week. As a result, the satisfaction level increased (simulation 2 in Table 2).

Finally, the additional *weight* and *weekly budget* (simulation 3) were reconciled in a new simulation without major additional gains.

For ***family II*** case, Table 3 presents the results obtained for the original model and for some additional simulations that were made from the calculation of the *shadow prices* of the variety and the ease of preparation "resources". These results are now explained in more detail:

(i) Analysing *variety* shows that the increase of one unit (i.e., the possibility of repeating a meal three times a week instead of twice, except for the takeaway options) on the right-hand side of inequality (13), enhanced the objective function by 0.690 (shadow price of the "variety" resource). By repeating an alternative twice in the same week, we ended up with a variation of 26 different alternatives among the 49 served. However, by serving the same alternative three times, the variety decreased to 18 in the week. This had the advantage of reducing the time needed for food preparation, but at the same time, it reduced the diversity of alternatives served during the week (simulation 1).

i. For the *ease of preparation*, reflected through inequality (11), the shadow price emerged as null, meaning a non-active restriction (slack > 0). In this context, dedicating more time to food preparation does not increase the perception of the meal being healthy. However, if we consider simulation 1, this constraint becomes active and the particular cook's dedication would result in an increased perception of the meal being healthy (simulation 2).

ii. We also combined both changes above (simulation 3): the increase of repeated meals (*variety*) and the dedication for preparation (*ease of preparation*). The result was a re-arrangement of dessert alternatives with almost null impact, of 0.007, on the objective function in relation to simulation 1.

Table 3. Results and simulations (Family II).

	Option (*i*)	Model	Original	Simulation 1 (Variety = 3)	Simulation 2 (Ease = 119)	Simulation 3 (Variety = 3 & Ease = 119)
Breakfast	B1 (1)	x_{11}	2	1	2	1
	B2 (2)	x_{21}	2	3	2	3
	B3 (3)	x_{31}	0	0	0	0
	B4 (4)	x_{41}	2	3	2	3
	B5 (5)	x_{51}	1	0	1	0
Afternoon/Morning Snack	S1 (6)	x_{62}	2	3	2	3
	S2 (7)	x_{72}	2	3	2	3
	S3 (8)	x_{82}	2	3	2	3
	S4 (9)	x_{92}	0	0	0	0
	S5 (10)	x_{102}	0	0	0	0
	S6 (11)	x_{112}	0	0	0	0
	S7 (12)	x_{122}	0	0	0	0
	S8 (13)	x_{132}	0	0	0	0
	S9 (14)	x_{142}	2	0	2	0
	S10 (15)	x_{152}	2	3	2	3
	S11 (16)	x_{162}	2	0	2	0
	S12 (17)	x_{172}	2	2	2	2
Lunch	L1 (18)	x_{183}	2	3	2	3
	L2 (19)	x_{193}	0	0	0	0
	L3 (20)	x_{203}	2	3	2	3
	L4 (21)	x_{213}	0	0	0	0
	L5 (22)	x_{223}	2	2	2	2
	L6 (23)	x_{233}	2	0	2	0
	L7 (24)	x_{243}	0	0	0	0
	L8 (25)	x_{253}	1	0	1	0
Take-away	T1 (26)	x_{263}	1	0	1	0
	T2 (27)	x_{273}	0	0	0	0
Dinner	D1 (28)	x_{284}	0	0	0	0
	D2 (29)	x_{294}	2	3	2	3
	D3 (30)	x_{304}	0	0	0	0
	D4 (31)	x_{314}	0	0	0	0
	D5 (32)	x_{324}	2	3	2	3
Dessert	E1 (33)	x_{335}	2	3	2	3
	E2 (34)	x_{345}	2	3	2	3
	E3 (35)	x_{355}	2	3	2	2
	E4 (36)	x_{365}	2	0	2	0
	E5 (37)	x_{375}	2	0	2	0
	E6 (38)	x_{385}	2	3	2	3
	E7 (39)	x_{395}	2	2	2	3
Objective Function			**5.720**	**6.410**	**5.720**	**6.417**

5. Discussion

This study explored an optimal way of planning and implementing an appropriate, health-conscious diet during the COVID-19 lockdown period. Using a participatory set of methodological steps, we made available a model tailored to two middle-class families comprising of working professionals with young children. Our main purpose was to offer a dietary decision support during the lockdown period that also respected the unique characteristics, values and needs of each family. For this, we combined Analytic Hierarchy Process (AHP) and its parsimonious variation (PAHP) with linear optimisation applied to a weekly menu that accommodated variations in similar dishes.

Although both families involved in this study are middle-class, the model can be adapted to other family types/classes. Importantly, the main beneficiaries of this study are families open to discussion regarding their meal preparation and conscious diet plans.

During the intervention we received positive feedback from the participating families. This was possible as the complete OR intervention (Lamé et al., 2020) of the proposed model was successfully tested and applied within two young family settings in Brazil. Importantly, the families appreciated not only the developed menu but also other desirable results that this approach yielded. The key elements of the participatory approach used in this intervention are summarised as follows:

Firstly, the ***reflection*** of the members of both families on a seemingly routine and minor issues related to food planning and preparation resulted in re-evaluating the time spent on these tasks. The families started to see this time as a valuable investment into improved health, immunity, family union and happiness. This also supports the argument by McIntosh et al. (2010), who points to food being increasingly perceived as an expression of affection which provided comfort to the members of a family unit (McIntosh et al., 2010)

Secondly, the experience of the decision-making process increased the ***commitment*** of all those involved, especially children (and adults with unhealthy eating habits), who were listened to and encouraged to think about the subject.

Thirdly, the participatory approach enabled the design and use of an easy tool to ***facilitate*** the day-by-day food planning and preparation. This was especially helpful for the person/people responsible for cooking activities. Among other tasks, it included making shopping list, going to grocery stores, and cooking. Subsequently, this tool provided a weekly menu, which encouraged a family decision-making process in these busy pandemic times.

The contemporary focus on the diet decision-making process during the pandemic might be viewed as limiting the scope of the study. However, by modifying elements, the proposed model can be easily adapted to other contexts and scenarios. These include but are not limited to (i) developing lean menus in restaurants and involving customers, (2) involving patients in hospital menu planning, (3) involving guests (at greater lengths than currently practiced) in menu planning in hotels, or (iv) involving passengers for airline catering.

Furthermore, the parameters of the model can be adjusted accordingly. For instance, the planning horizon can be increased along with the treatment of a subjective question in the objective function, which can also be replaced according to the circumstances to be addressed. Moreover, the family unit, (in this case, comprising a few members), could also be substituted with a larger group, or even a group of families or a community. This adaptability provides a scope for relevant policy implications.

In particular, the results of the present study point to a need to promote conscientious food choices and planning practices by families in the time of the pandemic and beyond. This further calls for an involvement of government agencies in the provision of programmes towards food literacy, especially in the context of ensuring a sustainable dietary pattern adoption (Springmann et al., 2021), a subject discussed by various commentators (Palumbo et al., 2019; Steils & Obaidalahe, 2020). This is a complex task which involves bringing together multiagency efforts. Lasting and sustainable, resilient food education implies not only formal learning, but also understanding the dynamics of family life, which in turn requires time and dedication, and increasingly difficult time management for parents juggling with multiple tasks such as home-schooling and working from home. Although the discussion of these issues reported in this paper took place *at home* and was based on the experience of only two families, the project not only proposed an initial guide for an accessible participative approach, but it also provided an insight into expanding this approach further by invoking social factors that must be considered in order to encourage wider communities to plan and change their eating habits with the aim of improving their health and well-being in difficult times where there is a continuous increase in the basic food products price (De Sousa, 2020). Hence, we believe that the exercise promoted in this article provides a stimulus for the discussion of government measures to support families with working parents in these difficult times.

6. Conclusions and further research

Food is a subject that is part of our daily lives and a vast field to be explored. The paper examined the relevant problem of food planning in times of the pandemic by proposing and testing a *participatory linear programming model* that maximises preferences in the diet subject to certain constraints reflecting the lockdown-specific context. The model enables quick creation of satisfying weekly menus and shopping lists, whilst simultaneously enabling the participation in the community and supporting the most vulnerable. The application of the model resulted in positive feedback from all decision makers, who highlighted its benefits in bringing family members together. The participatory character of the approach also enabled the family members to re-discover the importance of values that food promotes.

Given this positive feedback, the future research could explore how to successfully implement the proposed method in practice by extending its applicability to a wider range of settings, including group of families or even communities. Such examination could be conducted in the context of the present pandemic or could be modified to reflect constraints pertaining to other potential risks. From the national policy goal's point of view, this avenue of research could contribute to the sustainability debate in the context of dietary pattern.

Note

1. Only the drink is considered in the weight.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A. Detailed meal information

Table A1. Detailed meal information (family I).

Option (*i*)	Meal *j*	Description	Weight p_i(kg)	Price b_i(BRL)	Calories c_i(kcal)
B1 (1)	Breakfast/Snack	Coffee & milk, fruit, Brazilian cheese bread	1,18	10,05	2.219,6
B2 (2)	Breakfast/Snack	Coffee, cereal with yoghurt, fruit	1,55	15,60	1.834,0
B3 (3)	Breakfast/Snack	Coffee & milk, fruit, dark chocolate cookie	1,02	15,40	1.046,0
B4 (4)	Breakfast/Snack	Coffee & milk, fruit, chocolate-hazelnut waffle	1,10	20,12	1.710,7
L1 (5)	Lunch/Dinner	Bolognese pasta, fresh salad	1,71	39,58	3.284,5
L2 (6)	Lunch/Dinner	Cornmeal mush with chicken ragout, fresh salad	1,25	32,02	1.834,0
L3 (7)	Lunch	Rice, grilled fish, banana chips and vegetables	1,26	39,87	2.673,7
L4 (8)	Lunch	Rice, beans, sausage, scrambled eggs, salad	1,09	10,31	2.490,9
L5 (9)	Lunch/Dinner	Home made hamburguer	1,50	30,74	2.771,0
S1 (10)	Afternoon Snack	Pop corn, juice	1,25	10,10	1.250,0
S2 (11)	Afternoon Snack	Chips, fresh fruit	1,17	10,85	1.335,4
S3 (12)	Afternoon Snack/Breakfast	Granola & yoghurt bowl, fresh fruit	1,92	23,71	1.647,0
S4 (13)	Afternoon Snack	Açai berry sorbet with milk powder	0,97	24,2	1.842,6
D1 (14)	Dinner	Tuna bruschetta, juice	1,37	37,06	2.007,5
D2 (15)	Dinner/Lunch	Small pizza, juice(salty/sweet)	2,24	34,51	3.292,0
D3 (16)	Dinner/Lunch	Vegetable soup with pasta, toast, water	1,56	16,87	2.261,5
D4 (17)	Dinner/Lunch	Cheese and Turkey ham tapioca crepes, juice	1,89	31,20	3.397,0
Y1 (18)[1]	Delivery	Margherita pizza, juice	1,15	44,13	2.284,0
Y2 (19)	Delivery/Lunch	Sfihas (meat, cheese e broccoli), juice	0,60	78,36	2.760,0
Y3 (20)	Delivery/Lunch	Hamburgers, soft drink	0,60	37,80	2.231,0

Table A2. Detailed meal information (family II).

Option (*i*)	Meal *j*	Description	Ease of preparation index
B1 (1)	Breakfast	Coffee & milk, egg, nuts	2
B2 (2)	Breakfast	Coffee, banana & avocado milk	2
B3 (3)	Breakfast	Coffee, honey yoghurt	1
B4 (4)	Breakfast	Coffee, yoghurt with fresh fruits	2
B5 (5)	Breakfast	Coffee, yoghurt with dried fruits	1
S1 (6)	Morning/afternoon snack	Tea and boiled egg	2
S2 (7)	Morning/afternoon snack	Fresh fruits	1
S3 (8)	Morning/afternoon snack	Nuts	1
S4 (9)	Morning/afternoon snack	Tea and home-made carrot cake	3
S5 (10)	Morning/afternoon snack	Tea and home-made brownie	3
S6 (11)	Morning/afternoon snack	Tea and bought cake (orange/chocolate)	1
S7 (11)	Morning/afternoon snack	Tea and Brazilian cheese bread	3
S8 (12)	Morning/afternoon snack	Tea and sweet brioche	1
S9 (13)	Morning/afternoon snack	Cocoa milk	1
S10 (14)	Morning/afternoon snack	Coconut milk & coffee	1
S11 (15)	Morning/afternoon snack	Popcorn	2
S12 (16)	Morning/afternoon snack	Tea, rice cracker and butter	1
L1 (17)	Lunch/Dinner	Sweet potato puree, ground beef and salad	3
L2 (18)	Lunch/Dinner	Chicken thigh with tomato sauce and potatoes	4
L3 (19)	Lunch/Dinner	Codfish, potatoes and carrots	4
L4 (20)	Lunch/Dinner	Rice with peas, tuna, eggplant salad	2
L5 (21)	Lunch/Dinner	Rice, beans, beef steak and tomato/lettuce salad	3
L6 (22)	Lunch/Dinner	Salmon, grilled potatoes and tomato/cucumber salad	2
L7 (23)	Lunch/Dinner	Tomato sauce pasta, shrimp and salad	3
L8 (24)	Lunch/Dinner	Omelette, rice and salad	2
T1 (25)	Take-away (Lunch)	Barbecue	2
T2 (26)	Take-away (Lunch)	Packed Lunch	1
D1 (27)	Dinner	Pita sandwich	2
D2 (28)	Dinner	Zucchini and gorgonzola risotto	2
D3 (29)	Dinner	Cheese, olives, nuts, dried fruits and pickles platter	1
D4 (30)	Dinner	Home-made mozzarella pizza	3
D5 (31)	Dinner	Vegetable soup	3
E1 (32)	Dessert	Fresh fruits	2
E2 (33)	Dessert	Dried fruits	1
E3 (34)	Dessert	Chocolate bar	1
E4 (35)	Dessert	Guava pasta	1
E5 (36)	Dessert	Milk sweet	1
E6 (37)	Dessert	Nut candy	3
E7 (38)	Dessert	Peanut candy	2