Assessing Nutritional Adequacy of a Diet using Multicriteria Analysis

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1 Introduction

It seems difficult for consumers to adhere to the dietary guidelines issued by national health institutes. As can be seen from, e.g., [1], the consumption of saturated fatty acids of approximately 90% of the adult Dutch population exceeds the upper limit. This implies that a large part of the Dutch population could benefit, in terms of health effects, from improved dietary habits. Dietitians play an important role in improving this situation. However, their reach is limited in the sense that they cannot contact every consumer on a daily basis over a long period. A digital companion can make the difference here. Such an application can support dietitians in their daily practice and empower consumers to make better food decisions by themselves. At the same time, we see that many of today's dietary apps give *general* advice, not tailored to individual health status and preferences. To have real impact, the apps need give *personalised* dietary advice.

To decide on what is the best diet for an individual, many aspects have to be taken into account and their combined impact has to be expressed in a single indicator. A single overall nutritional indicator makes it possible to decide how well-suited a diet is for a specific individual. It can, for example, be used to assess the overall nutritional effect of replacing individual food products in the habitual daily diet by alternatives. We expect that this leads to more acceptable and effective alternatives than using an indicator independent of someone's habitual food intake and health status, based for example on Nutriscore [REF]. Our objective is to create a *pragmatic* approach for optimising personal diets, that permits the design of a next generation of personalised dietary apps.

In this paper we define an *nutritional adequacy* indicator*,* together with an algorithm that computes the value of this indicator from the amounts of different nutrients in a diet. The algorithm applies a specific method for multicriteria analysis. Although for now we focus on the effect of macronutrients, our algorithm is scalable to include other criteria, such as micronutrients, personal and social preferences, or the carbon footprint of a diet. To give insight into how a diet may be improved, our algorithm assesses the *nutritional adequacy* of a daily food intake, based on lower and upper limits for each macronutrient, e.g. the recommended daily allowance (RDA) or the adequate intake (AI) as set by the Dutch Health Council [REF]. This means we consider personalisation along the dimensions of health status, health goals, habitual diet, temporary diet, etc, but not (yet) on consumer preferences, social and cultural context, current situation and location, etc. In fact we apply a separate method for handling the latter aspects, based on filtering of preferred food items in an overall diet [REF].

The Dutch Healthy Diet Index [9] provides a method to measure the adherence of a diet to the general Dutch guidelines. It is a combination of level of physical activity, intake levels for a few food categories (vegetables, fruit, fish, acidic drinks and foods) and for a few nutrients (sodium, alcohol, SFA, TFA, and fibre). Considering only these parameters already gives a high correlation to adherence to the guidelines, and to nutrient density. Note that this index provides an indication of how well a diet adheres to general guidelines, but does not take any personalization into account.

With our personalized dietary advice tools, this generic translation can be replaced by personalized suggestions to consumers in the form of alternative food products. We do this by sorting the alternatives for an original product based on the outcome of the multicriteria model. The consumer decides which of the products in his or her original food intake should be replaced by an alternative product (though our algorithm could also be used to highlight the original product for which replacement by an alternative would contribute most to a better score). Our motivation is in guiding people to gradually make steps towards a healthier diet and we deliberately keep the consumer in the loop.

2 Method

In our approach we assume that we know for each macronutrient, such as protein, fibre, saturated fatty acids, cholesterol, water and carbohydrates, which intake levels are (in)adequate for an individual, taking over a certain period of time. Since such information is still scarce and the way in which to combine them into a combined impact is not fully understood yet, we have to make several simplifying assumptions. It appears that the method of Balance Of Acceptability (BOA) [2] for multicriteria assessment provides a pragmatic approach that is well suited for our objectives. BOA was defined in terms of the *acceptability* of a proposed solution by decision makers, based on a combined set of key indicators. We use this way of computing acceptability to determine the overall nutritional adequacy of a diet. BOA has a number of interesting features:

- First, it *linearizes* the adequacy curves (Figure 1) of the underling criteria (in this case the available macronutrients), which allows us to summarize the curve in a few critical values (initially only one lower limit and one upper limit).
- Secondly, it *re-scales* the indicators to a range between 0 and 1 to make them comparable.
- Finally, it permits *different ways of combining* the underlying criteria for example by taking a weighted average, or minimum and maximum values. This can be different for different subsets of criteria.

The different elements of the BOA method are not unique by themselves, as they are common in many multicriteria approaches, but the combination of them has allowed us to make appropriate and transparent simplifications in a pragmatic manner.

2.1 Dietary reference values

Before discussing the integration of the different nutritional values into one overall nutritional adequacy indicator, we discuss how the individual adequacy curves are reduced.

In the *Voedingsnormen* documents [REF], the Dutch Health Council provides a systematic review of the available scientific knowledge on the relation between nutrition and chronic diseases, and accordingly establishes dietary reference values for the population of the Netherlands. The dietary reference values for protein have recently been reviewed for the whole population [5]. For the other macronutrients, the dietary reference values from [6] are still applied. They differentiate between age, weight and gender, allowing for some level of personalisation. These dietary reference values are quite similar to those of EFSA [7]. For micronutrients, these dietary reference values have recently been updated both for pregnant women [3] and for the general adult population [4]. These dietary reference values differentiate between gender, age category and whether a person is pregnant or lactating or not.

Figure 1 shows the relations between the different dietary reference values. Definitions of these reference values may be found in, e.g., [8]. For our calculations, we make use of the

- Recommended Daily Allowance (RDA[1]), defined in [8] as the average daily dietary intake level that is sufficient to meet the nutrient requirement of nearly all (97.5 percent) healthy individuals in a group. EAR is the Estimated Average Requirement, and RDA = EAR + 2 times the standard deviation.
- Adequate Intake (AI), used by the Health Council when an RDA cannot be determined. The AI is based on approximations of nutrient consumption by a group of healthy people. In the current paper we only use RDA to indicate the adequate intake level.
- Tolerable Upper Intake Level (UL[2]). This is defined in [8] as the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects to almost all individuals in the general population. The UL is based on the No Observed Adverse Effect Level (NOAEL) and/or the Lowest Observed Adverse Effect Level (LOAEL). The UL is set lower based on a number of uncertainty/safety factors off the NOAEL or LOAEL.

We use RDA as a lower limit per nutrient, and UL as upper limit. This means that if the daily intake is between these limits, the nutritional adequacy is optimal for this nutrient.

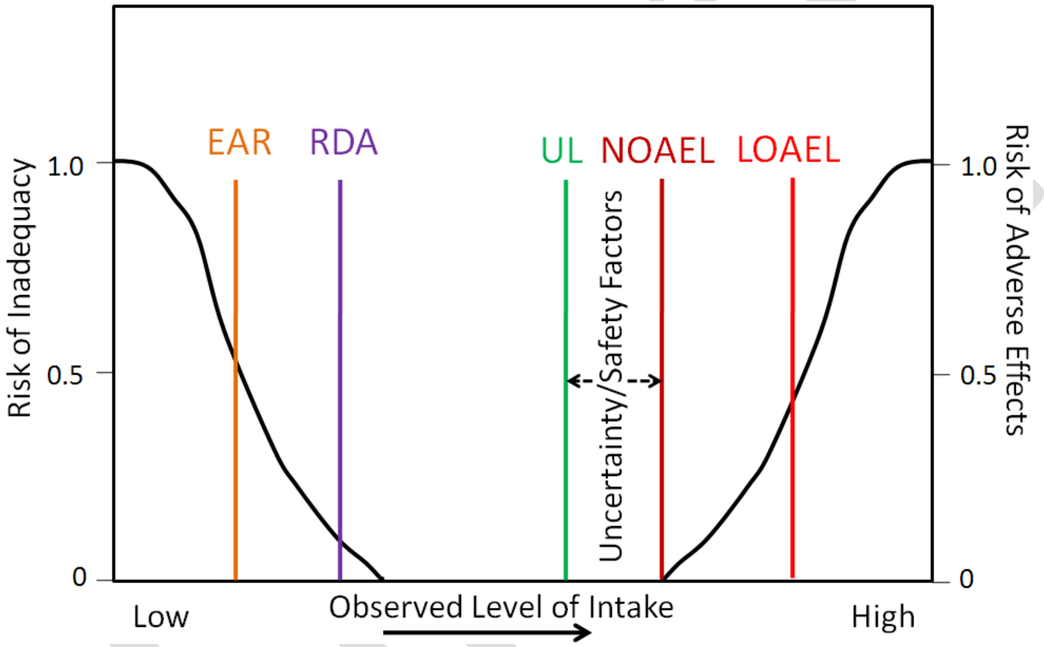

Figure 1: The different dietary reference values, picture from https://open.oregonstate.education/humannutrition/chapter/micronutrients-overview-dietary-reference-intakes-dris/

As we express our overall indicator in terms of nutritional adequacy rather than risk, our first step is to invert the graph of Figure 1, as shown in Figure 2, where nutritional adequacy equals one minus the risk of inadequacy.

[1] In Dutch called ADH for *Aanbevolen Dagelijkse Hoeveelheid*
[2] AB for *Aanvaardbare Bovengrens* in Dutch

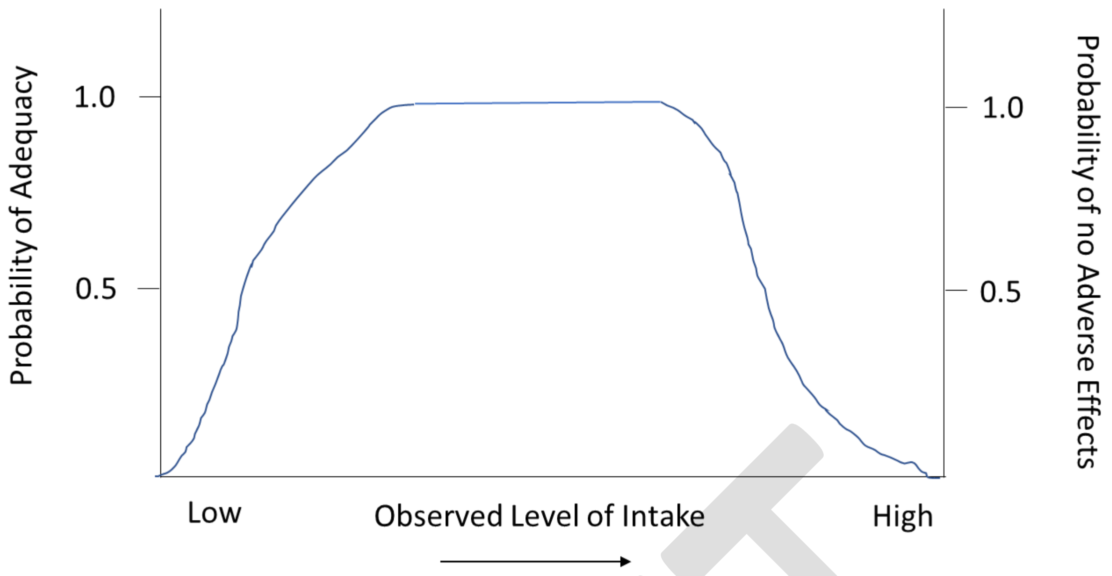

Figure 2: Probability of nutritional adequacy

The next step could then be to take the upper and lower limits as strict boundaries of adequate intake. Linearizing would result in a block-shaped curve, where the adequacy is 1 for the 'healthy' intake range between RDA and UL and 0 on both sides outside that range. However, this would be an oversimplification of the left side of the curve, as it does not represent that eating some proteins for example is better than none proteins. We can represent this without the need for additional limits, by assuming that the linear curve on the left side starts at 0 and gradually increases to the adequate level of 1 at the lower limit RDA. On the right site we do not have such a natural extra reference point. So we interpret the UL as a strict upper limit, which you should not exceed. This is in line with the definition that the UL is the highest level of intake that is likely to pose no risks. This results in the approximation shown in Figure 3.

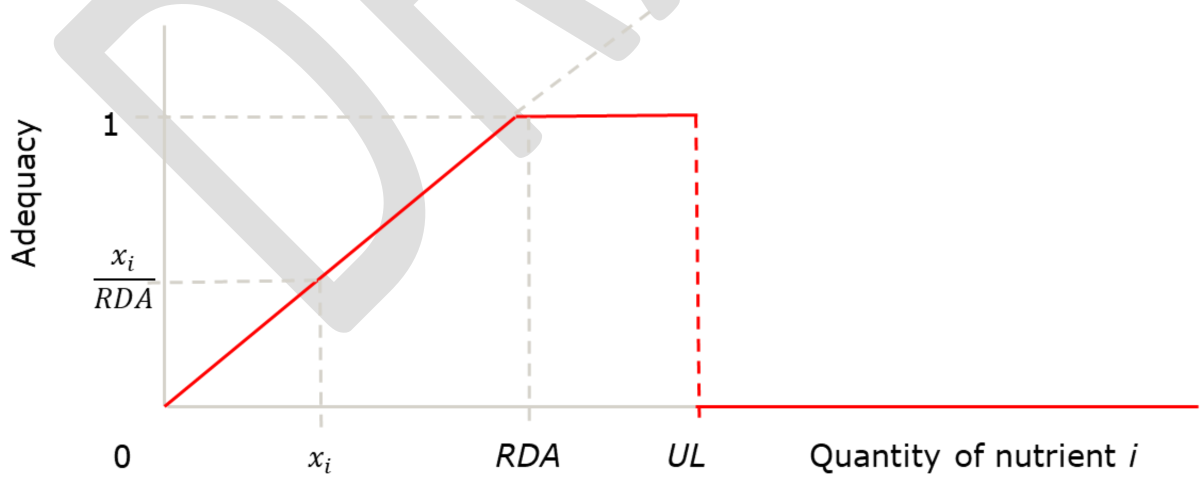

Figure 3: Nutritional adequacy curve per nutrient

2.2 Calculation of nutritional adequacy score

When applying multicriteria analysis, one has to decide how to combine the values of the individual criteria (nutrients) into one overall adequacy score covering all involved nutrients. This can be done in different ways.

One issue is whether good adequacy scores for one nutrient are allowed to 'compensate' bad scores for another nutrient [2]. Even though strictly speaking one nutrient cannot compensate for the specific effect of another, it may do so in terms of the overall health impact of a diet, and so in terms of the overall nutritional adequacy.

On the left side (regarding the lower limits RDA), we want to express that we to allow some compensation of values among different nutrients. For example, a diet can be sufficiently adequate if it scores modest on fibre but high on protein: it is not the case that the modest score on fibre fully determines the overall nutritional adequacy score. The overall nutritional adequacy score is computed by taking a *weighted sum* over all nutrients, provided that these nutrients are in the safe range, so below the tolerable upper intake level UL.

As far as the *weights* of the averaging is concerned, these enable further personalisation, beyond age, weight and gender that were needed for determining the specific limits of the individual nutrients. These weights determine the influence of the adequacy of the different nutrients on the overall nutritional adequacy score and may reflect someone's personal goal by emphasizing certain nutrients. For example, people with Irritable Bowel Syndrome (IBS) may give a higher weight to fibre intake. The dietitian is foreseen to play an important role when deciding about the personal weights for a specific consumer. In the future, these weights even might be automatically derived based on a patient's health status.

On the right hand side (regarding the upper limits UL), we want to express that we have no compensation at all. If one or more nutrients are above the tolerable upper intake level, the whole diet has become unacceptable, so the overall nutritional adequacy score becomes 0.

2.3 Outline of algorithm

This results in the following outline of our algorithm. To calculate the overall nutritional adequacy score NA of a menu with intake levels $x_i..x_n$, we need to calculate some intermediate results.

First, for each nutrient i, we calculate two values. The first value, called the RDA-score $NA_{RDA}(i)$, expresses how well the intake x_i of nutrient i is on its way towards reaching the RDA value for this nutrient. It is defined as $NA_{RDA}(i) = min\left(\frac{x_i}{RDA_i}, 1\right)$, which does the scaling and cut-off. A graph of this function is shown in Figure 4.

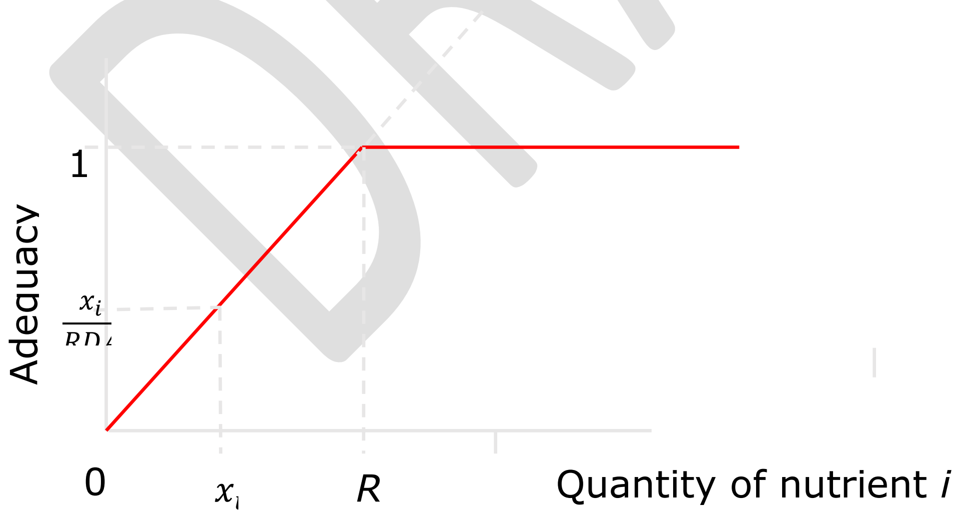

Figure 4: RDA-score for nutrient i

The second value, for intake greater than RDA, is determined from whether the intake x_i for this nutrient is either below or above the upper limit UL. If x_i is larger than the upper limit it is defined to be 0, else it is 1: $if\ x_i > UL\ then\ NA_{UL}(i) = 0\ else\ NA_{UL}(i) = 1$. Note that the RDA value of nutrient i does not play a role here, as this value is taken into account in the RDA-score. This function is depicted in Figure 5.

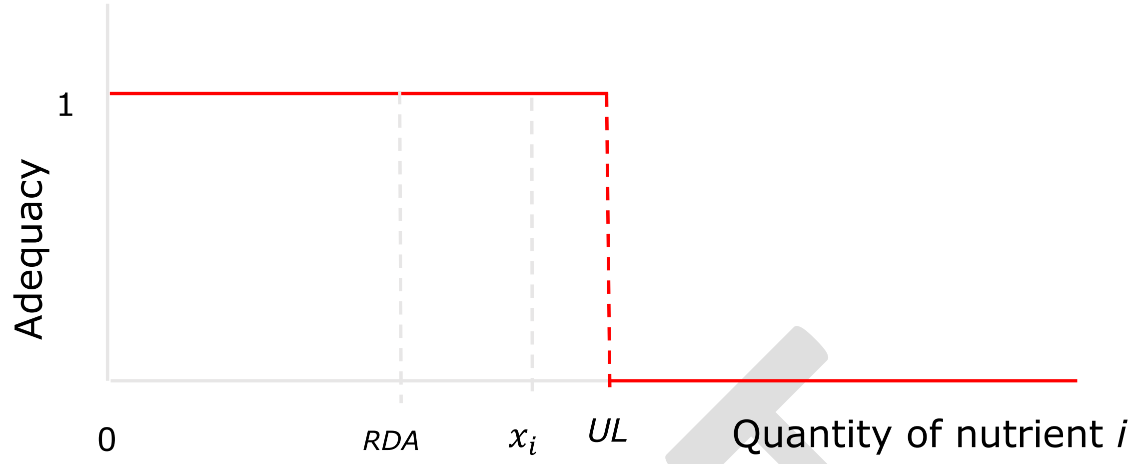

Figure 5: UL-score for nutrient i

Second, from these nutrient-specific values $NA_{RDA}(i)$ and $NA_{UL}(i)$ we calculate the overall RDA respectively UL adequacy scores for the complete diet. The overall RDA-adequacy of the diet is defined as a *weighted sum* over the RDA-scores for all nutrients, i.e. $NA_{RDA,tot} = \sum_{i=1}^{n} w_i\, NA_{RDA}(i)$, where n is the total number of nutrients, and w_i is the (personal) weight defined for nutrient i. Here we see that, in contrast to the case of UL-scores, we have that RDA-scores for the different nutrients can partly compensate each other. If the consumption of one specific nutrient, e.g., protein, is equal to the desired RDA for protein, while the amount of, e.g., carbohydrates is below the RDA for carbohydrates, a reasonably good intermediate RDA-adequacy may still be reached.

The overall UL-adequacy of the diet $NA_{UL,tot}$ on the other hand is defined as the *minimum* of the UL-scores for all nutrients, i.e. $NA_{UL,tot} = \min_i NA_{UL}(i)$. This means that if the consumption of any nutrient exceeds its upper limit, the overall UL-adequacy for the diet will immediately be 0. In other words, the UL-scores for different nutrients cannot compensate each other. The reason for taking the minimum here, is that we want to prevent any nutrient to pass UL, which could potentially be harmful. Only if the consumption stays below the upper limit for all nutrients, the overall UL-adequacy $NA_{UL,tot}$ for the diet will be 1.

Finally, the overall nutritional adequacy of a diet is calculated as $NA_{tot} = \min(NA_{RDA,tot}, NA_{UL,tot})$. This means that if no nutrient has passed its upper limit the overall adequacy is a the weighted average of all RDA scores over all nutrients, else it is 0.

Summarizing, the applied *compensation* tree of indicators is as follows:

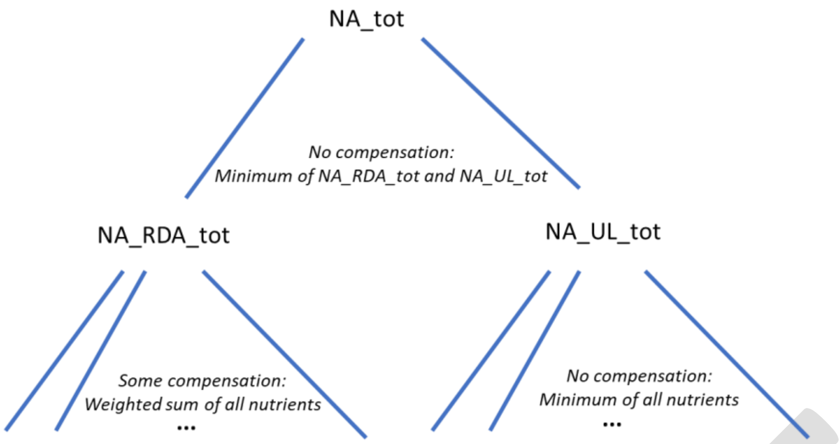

Figure 6: Compensation tree of indicators, with for each branch a specific compensation level

As output, the algorithm calculates an overall adequacy score of the daily food intake, where 1 indicates adequate and 0 indicates inadequate or potentially harmful.

3 Discussion

A full evaluation of the proposed algorithm would require an extensive intervention study with a substantial number of subjects who would the given advice and be monitored for their health status. However, as there are many other factors that would play a role, setting up such a large scale and expensive study is not opportune. We can however compare our results to existing dietary advice. An important candidate for such a comparison is Eetmeter, which is provided by the Netherlands Nutrition Centre. However, as Eetmeter doesn't give a total score, we can only compare at the level of individual criteria.

Another option was to discuss the outcomes of this approach with dietitians who give advice to consumers on a daily basis. This has revealed a number of issues, relating to the way in which the adequacy score for each nutrient is determined:

- The immediate decline to zero above UL suggests a severe risk when this limit is passed for any nutrient. In our application that uses this algorithm this means that some food items are already forbidden if they cross the limit slightly. However, in practice this decline is almost never that abrupt. In fact, a more precise definition is required for this limit. In addition, probably a second upper limit is required, such that we get a gradual drop from 'less healthy' to 'causing serious damage'.
- Nutrients that are always more or less unhealthy, such as sugar, in our limited model should have both the RDA and UL at zero: they have no 'adequate' range and are in fact unhealthy. Also here, a second upper limit is required to represent that already from zero intake the nutrient is increasingly unhealthy.
- It is a question whether we need to be able to have an area of adequacy=0 at te left side of the curve (no immediate increase at x=0)? This would mean we also need a second value for RDA, below which the nutrient has no health impact at all. A application that bases its advice on such a curve should be able to decide whether adequacy=0 means that the nutrient is too low or too high, as the value itself can't tell.
- The energy value is a special case. Currently we take the 'RDA' for energy intake from the Harris-Benedict formula [REF], and estimate the upper limit as UL=RDA+20%. However, this is not realistic. For example, for energy we would also need a gradual decline after UL. Probably energy should not be considered at all as an independent factor in the MCA, since it already implied by the absolute values of the macronutrients.
- One can argue that not only the weights but also the RDA and UL should be personalised (for example by a dietitian).

- We could extend the set of criteria to include consumer preferences, for example 'taste', 'CO2 footprint'. These could then be combined in a single sub-criterium 'acceptability', which is the combined with the nutritional criteria. The general BOA-method has the possibility to take the maximum value of the underlying criteria (full compensation) instead of the weighted average or zero, as we have done so far. This does not work for nutrients, but may work for preference attributes such as 'taste' and 'price'.

4 Conclusion

The BOA method appears to be a suitable, pragmatic tool to compute nutritional adequacy. Our algorithm can handle the complexity of multiple nutrients and multiple food items at the same time. However to get a realistic overall value, it needs improvement with respect the definition of the critical values for each nutritional value. Determining an overall score for a diet is hard for dietitians to do manually due to it complexity. In fact, implementing this algorithm could shift the role of the dietitian from suggesting diet changes to setting important parameters in the algorithm for their client, such as the personal nutritional weights and personal lower and upper limits for specific nutrients. At the same time, it helps explicating the – often implicit – choices of dietitians.

5 Bibliography

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