An Application of a Fuzzy-based Optimisation Model for Selecting Food Products based on Cost and Nutrition

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ABSTRACT:

For consumers with limited financial resources, both the total healthiness of the food product and the affordability are equally critical determinants in choosing basic food products. The application of fuzzy based methods enables a systematic selection of food products based on cost and nutrition factors considering subjective judgements and imprecise nature of decision inputs. In this study, each type of nutrient and the price of food item are expressed as fuzzy sets. The total nutritional value based on the harmonic mean of nutrients in the food product indicates its degree of healthiness. The contextual knowledge and domain expertise in health and diet are integrated to generate a set of fuzzy rules that identifies best purchase decisions. By taking wholemeal bread brands in supermarkets as an example, the empirical application of the proposed method is illustrated. This method can accommodate more decision variables and has the flexibility to accommodate different socio-economic conditions and consumer requirements by changing input variables and fuzzy rules.

Keywords: Food purchase decisions; Fuzzy expert system; Nutrition; Food cost

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Purchase decisions about food items have become complex due to the enormous variety of available products of any particular food item in the market. These purchase decisions are influenced by a multitude of factors including, price, nutrition knowledge and level of literacy of the purchaser, freshness of food, food beliefs, in-store stimuli and packaging (Monroe 1973; Silayoi and Speece 2004; Berenji 2007; Gau and Viswanathan 2008; Abratt and Goodey 1990). For some consumer groups and public nutrition programs such as those in school canteens, aged care facilities or boarding houses, nutrition as well as price are especially significant factors in the food selection decision because funds and/or subsidies are often quite restricted.

Optimizing nutrient intake has been studied using different approaches. Fuzzy decision making for the optimization of nutrition education includes how the fuzzy approach can be used in nutrient intake recommendations (Hensel et al. 1999). The methodology determining the recommended dietary allowances improves nutrient intake through small changes in food choices thus allowing a higher chance of acceptance among consumers. In comparison with non fuzzy methods in diet optimization, the nutrition requirement of a person with considerable diet changes, the fuzzy based approach provides improvements for intake of many nutrients and has the advantage of being able to incorporate small variations for optimised diets from corresponding actual diets (Wirsam et al. 1997).

When the cost of food leads to discriminatory effects of competitive foods resulting low participation of intended community (Sklan and Dariel 1993) in public nutrition programs , knowledge about the range of food products that are both competitive in terms of price and nutritional value means variety can be added to meals. Without this knowledge, the objectives of public nutrition programs such as those in school canteens and aged care facilities can be harmed or lost. Several previous studies attempted to meet the nutritional needs at minimum cost. A study using a computerized model for planning diets at minimum cost while supplying all nutritional requirements, maintaining nutrient relationships and preserving eating practices was based on a mixed-integer linear-programming algorithm (Sklan and Dariel 1993). A similar method has been adopted for meal recipes for optimization based on the cost, cooking and preparation time (Leung et al. 1995). However, these methods do not address the fuzzy nature of nutritional requirement values.

Fuzzy based optimisation and balancing of the menu have been used in practice. For example, one nutrition software application used fuzzy arithmetic to transform any meal into well-balanced status (Buisson 2008). An empirical adoption and extension of the fuzzy based method for nutritional requirements (Wirsam et al. 1997) was used in menu planning in boarding schools (Kljusurić & Kurtanjek 2003) and in analysing and evaluating the nutritional quality of menus provided for kindergarten children (Rumora and Kljusurić 2009). The fuzzy model represents the recommended energy and nutrition intake more adequately than the dietary recommendation intake presented as crisp numeric values (Kljusurić & Kurtanjek 2003). The fuzzy logic control system models the membership functions of fuzzy sets for price of meals, energy, organic-chemical structure and meal preferences and meal optimisation is based on these variables. They referred to a software product that optimises multiple goal functions based on the criterion of Prerow value. The fuzzy expert system method was used in another software application for dietary analysis to map the nutritional state of an individual using a food diary and compared the nutritional intake levels with the recommended levels (Heinonen et al. 2009). However, our literature search indicated that although multiple approaches, including the fuzzy approach, have been developed and employed in various situations, the use of fuzzy reasoning based on expert rules to obtain a crisp value and therefore support decision making based on multiple decision inputs, has not received the attention it deserves. In brief, this study adopts a fuzzy rules reasoning approach for decision support, based on the price and nutrition level input variables that are fuzzified before matching with the expert rules, which are themselves fuzzy in nature. This fuzzy expert system approach has been used by the authors in developing a methodology to determine the caloric requirement of individuals that takes into account age, body mass index and the physical activeness (Nakandala and Lau 2012). In general, this research extends the fuzzy based approach to determine the overall nutritional value of a food item by considering all its nutrients (Wirsam et al. 1997) with the fuzzy expert system approach, to develop a method that supports decision- making, when both nutrition and price are significantly important.

Fuzzy Based Method

The previous use of fuzzy logic for decision-making in nutrition, demonstrated that there is no single optimal intake value but a range of intake values for a nutrient (Wirsam et al. 1997). Hence, there are overlaps between linguistic variables that are used to indicate the nutrient intake (Wirsam and Uthus 1996). Based on the Prerow method used in determining how closely a food type reaches the recommended nutrition, this paper develops a method that integrates both cost and nutrient optimisation for decision-making in food selection. The proposed method deviates from the previous method (Wirsam and Uthus 1996) and extending the Prerow method for optimising multiple goal functions (Kljusurić & Kurtanjek 2003) by adopting the fuzzy expert system method to optimise both price and the level of nutrition, allows the flexibility to match the different economic and social conditions of targeted consumer groups.

The fuzzy expert system allows the integration of expert data into the decision making and the process contains three main stages - data acquisition, fuzzy inference engine and defuzzification. In the data acquisition stage, an environmental study is done in order to understand the context and the situation/problem and to identify important input variables in the decision making process. Total nutritional value is not the sole determinant of purchase decisions when the budget is limited. Purchase decisions about food items are collectively influenced by price and healthiness of the products; these are the input variables of the proposed model. The raw data of input variables are collected as deterministic values known as crisp values. These crisp values are then converted into fuzzy sets that can be expressed, as in equation 1.

$$A = \sum_{i-1}^{n} \mu_A(x_i)/x_i \qquad (1)$$

Where A(x_i) is the membership function of element x_i in the universe of discourse when the support set is a finite set, X = {x_1, x_2, x_3, x_4 ……x_n}. Crisp values of individual nutrients are fuzzified and then assessed together to determine the level of healthfulness of the food item by calculating the Prerow value (Wirsam and Uthus 1996) as given in the equation 2.

$$PV = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\mu\tilde{A}_i(x_i)}} \tag{2}$$

Where PV is the Prerow value and x_i is the individual nutrient value.

Nutrient intakes are expressed as fuzzy sets and the harmonic mean of individual nutrients of a food item provides the overall nutrient value (or healthfulness) that feeds the fuzzy inference engine as an input variable for the decision-making process. The subsequent stage of fuzzy inferencing requires the fuzzy rule sets that are formulated by the knowledge experts in the domains of health and nutrition with the understanding of the socio-economic conditions of the target consumer groups.

Depending on the input variable values, applicable fuzzy rules are selected and fired to generate the output predicates. The fuzzy value of the output variable is generated using the Mamdani operator. In the defuzzification process, the output fuzzy values are converted back into crisp values by using the Centre of Area as given in the equation 3.

$$Y = \frac{\sum_{j=1}^{N} w_j \overline{C_j}\,\overline{A_j}}{\sum_{j=1}^{N} w_j \overline{A}_j} \tag{3}$$

Where w, C, A denote the weight, centre of gravity and area of each individual implication result respectively.

Construction of membership functions requires the dietary recommendations of each nutrient be known. The ‘Nutrient Recommended Values for Australia and New Zealand’ guide was consulted in seeking the recommendations specific to Australians (Australian Government 2006). Recommendations for total fat are not set as it is the type of fat that is critical in relation to physiological and health outcomes. Similarly, recommendations for carbohydrate are not set due to the limited data that exists. The dietary fibre requirement for adolescents (14-18 years) is set at average intake (AI) for girls 22g per day and for boys 28g/day. However, the upper intake (UI) levels are not specified and the AU/NZ guidelines states that “it is difficult to link a specific fibre with a particular adverse outcome… . A high intake of dietary fibre will not produce substantial deleterious effects when it forms part of a healthy diet, so no upper level intake is set…”(p48). The guidelines for protein intake set for the estimated average requirement (EAR) and recommended daily intake (RDI) for adolescent boys at 49g and 65g per day and for girls 35g and 45g per day. No UI for protein is set due to the insufficient data. For salt, the AI for all adolescents 460-920mg per day and the upper intake is 2,300 mg per day. For carbohydrate, the AI, EAR and AI are not set due to limited data exist on which to base an estimate requirements. Also it is inappropriate to set the UI for carbohydrate according to the AU/NZ guidelines. As described above, the recommended guidelines on AU/NZ nutrient requirements are incomplete and do not enable constructing localised dose-response curves. Thus the German nutrition recommendations (DGE 1992) are used based on the similarity between Australia and Germany as industrialised economies.

Results

We demonstrate the proposed methodology by evaluating wholemeal bread brands. Wholemeal bread brands with fortified nutrients are excluded to consider only the regularly present common nutrients of energy, carbohydrate, dietary fibre, protein, sodium and fat. Data were collected in three major supermarkets, namely Coles Supermarkets and Woolworths in Carlingford and ALDI Supermarkets in North Rocks on the 17th of August 2012. The Australian retail market is dominated by Coles and Woolworths with ALDI as an overseas entrant (Baker and Wood 2012). Both Carlingford and North Rocks are adjacent suburbs representing a typical urban suburb in Sydney. Prices are generally the same across stores of the same supermarket in urban suburbs in a state. Data collection was done on a day without any special events in order to avoid external effects on the product price. Since there are regular promotional sales, data were taken on the basis of regular prices of products despite that some products were on promotion on the data collection date. Since the number of wholemeal bread brands available in supermarket stores is limited a random selection was not suitable to apply. Hence data were collected on all unfortified wholemeal bread brands available in the three stores. Since the range of bread brands available in supermarket stores does not change frequently the collected data represent all commonly available products in a typical supermarket in an urban suburb in Sydney.

Historically, the average quantity of bread consumption was found to be 126g/head/day in the United Kingdom in 1980, 156g/head/day in Australia for 1972-1973 and 143g/head/day for urban groups in 1979 and 133g/head/day for rural groups in 1980 in Ireland (Downey et al. 1982). Based on this information, we assume the daily average consumption of bread per head is 136g that equals to two serves per day calculated on the average serve size of the sample items. Table 1shows the nutrient values and the price of average serve size of each bread type.

Wholemeal bread type	A	C	D	F	G	H
Energy (g)	1278.4	1400.8	1391.28	1332.8	1346.4	1347.76
Protein(g)	13.056	13.736	12.92	11.696	12.24	13.056
Fat, total (g)	2.176	4.76	2.856	2.448	2.584	4.896
Carbohydrate (g)	54.4	54.4	58.888	58.616	57.12	51.816
Dietary fibre (g)	3.264	8.84	9.112	5.848	8.704	8.024
Sodium (mg)	625.6	544	544	523.6	544	529.04
price per two average serves ($)	0.87	0.69	0.58	0.31	0.31	0.31

Table 1: Nutrient values and the price of 136g of each bread type

The membership function of the healthiness, H given by the Prerow value which is in the range of 0-1. The predicate functions as shown in Figure 1, were informed by the fuzzy membership functions for linguistic variables of nutrients developed by Wirsam and Uthus (1996).

$\mu h(H)$ = {CL,CR,BS,S,OP} where CL=Clinical, CR=Critical, BS=Barely Sufficient, S=Sufficient, OP=Optimal}

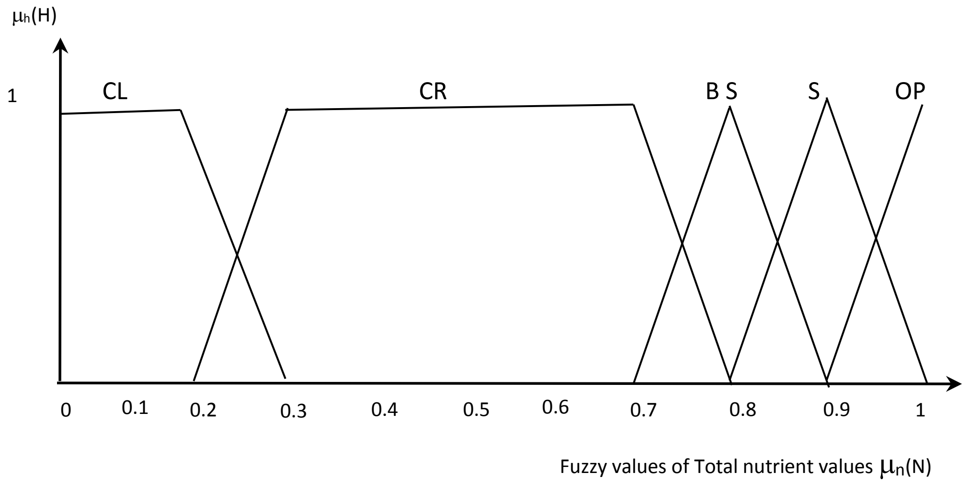

Figure 1: Membership values of the level of healthiness of bread

The price of a wholemeal bread loaf of 700g varies between $1.50 and $6.00 in supermarkets. Thus the price of two serves varies between 29 cents and $1.17. The price range for the analysis is considered to be between $0 and $1.50. The membership function, $\mu_p(P)$ of the input variable of price, P is shown in Figure 2.

$\mu_p(P)$={VC,C,A,E,VE} where VC=Very Cheap, C=Cheap, A=Acceptable, E=Expensive, VE=Very Expensive

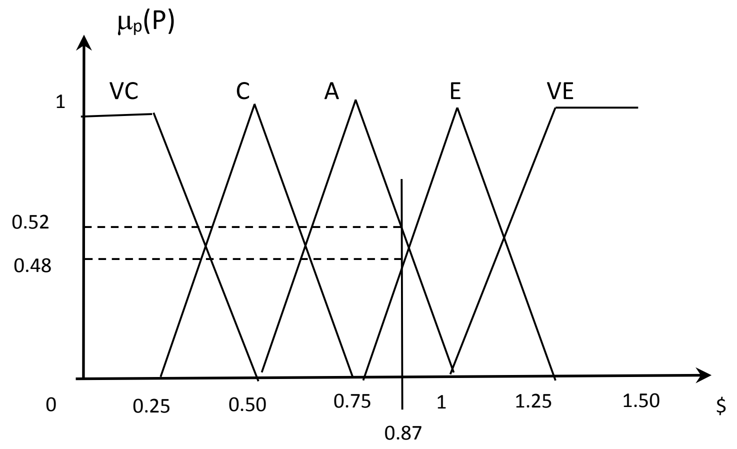

Figure 2: Membership function of price of 136g of wholemeal bread, P

The membership function of the output variable of the purchase decision, D is shown in figure 3.

$\mu_d(D)$={NC, NR, JR, R, HR, B} where NC=Not to be considered, NR=Not Recommended, JR=Just Recommended, R=Recommended, HR=Highly Recommended, B= Must Buy

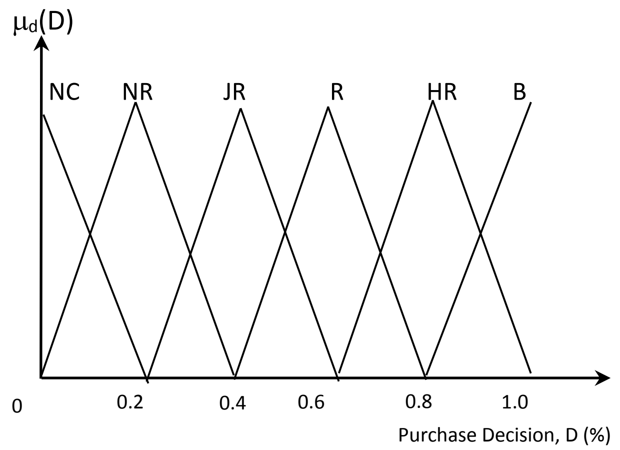

Figure 3: Membership values of the purchase decision, D

The fuzzy rule set that consists of if-then statements developed by knowledge experts in health and nutrition with a good contextual understanding of the socio-economic conditions of the target consumer groups is given in table 2. The fuzzy rules are for the two input conditions of healthiness and price of the type of wholemeal bread and the output of the purchase decision.

Decision, (D)	Healthiness, (H)				
Price, (P)	Clinical	Critical	Barely Sufficient	Sufficient	Optimal
Very Cheap	NR	NR	JR	HR	B
Cheap	NR	NR	JR	HR	B
Acceptable	NC	NR	JR	R	HR
Expensive	NC	NC	NR	JR	R
Very Expensive	NC	NC	NC	JR	JR

Table 2: Fuzzy rule table

The total healthiness of each wholemeal bread type is calculated by using the equation 1 as exemplified below for the sample A. The fuzzy sets for nutrients used in this study were adopted from the study by Wirsam et al. (1997). The raw value of each nutrient of each sample was converted into daily intake values based on the average adult diet of 8700KJ as used in all sample items. These crisp and fuzzy values of nutrients of sample A are tabulated in table 3. The intakes of carbohydrate and fat are converted into a percentage of energy intake in calories to directly read the fuzzy values from the fuzzy sets.

Nutrient	Crisp value	fuzzy value
Energy (calories)	7896	0.9
Protein (g)	47.43	0.9
Fat calories in % of energy intake)	21.38%	1
Carbohydrate calories in % of energy intake	59.65%	0.97
Dietary fibre (g)	11.2	0.74
Sodium (mg)	2576	0.975

Table 3: Main nutrients and fuzzy values of the sample A

The value of price, P which is $0.87 cuts the A predicate at 0.52 and E predicate at 0.48 in the fuzzy set shown in Figure 2. The total level of nutrition of the type A bread is calculated using the equation 2. The calculated Prerow value is 0.905. The membership value for input variable, total healthiness, cuts the S predicate at 1 in the fuzzy set which is shown in Figure 1. Based on these values two rules can be activated as shown in table 4 from the fuzzy rules sets in table 2. Fuzzy values are also generated by using the Mamdani Operator for implication as shown in table 3.

Rule #	'If' clause	'then' clause	Composition Results
1	If Healthiness is Sufficient and Price is Acceptable	Purchase decision is Recommended	1^0.52= 0.52
2	If Healthiness is Sufficient and Price is Expensive	Purchase decision is Just Recommended	1^0.48= 0.48

Table 4: Applicable fuzzy rules

These output fuzzy values and the predicates are aggregated to generate the final fuzzy set as shown in Figure 4.

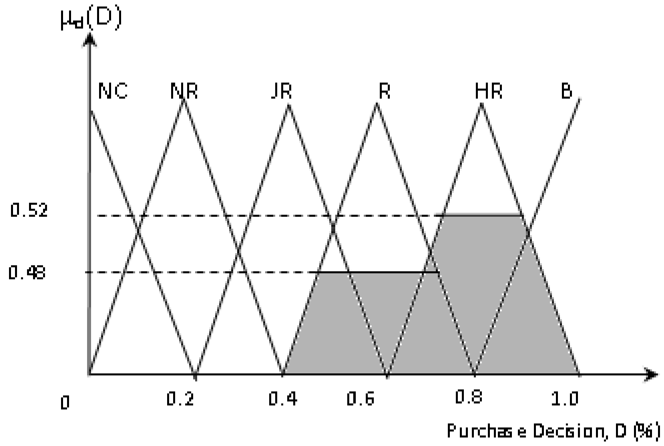

Figure 4: Aggregated fuzzy values of the output variable

The output fuzzy values are converted into crisp values by using the Centre of Area method as given in equation 3. The purchase decision for sample A is 46.10%. Similarly, the output values for all brands in the sample are calculated and given in table 5. With the highest output value, sample D is the optimum purchase because it provides the maximum healthiness at the lowest cost.

Wholemeal bread type	A	B	C	D	E	F
Prerow value	0.90	0.93	0.92	0.96	0.95	0.93
price per two average serves ($)	0.87	0.69	0.58	0.31	0.31	0.31
Purchase Decision	46.10%	72.51%	75.77%	86.23%	84.43%	83.45%

Table 5: Input and output values for all sample wholemeal bread types

Discussion

With the availability of numerous product brands for any given food type in the market, consumers require a systematic method of selection of the most appropriate product for their level of requirement and affordability. This study aimed to demonstrate how a fuzzy based method could be applied to systematically assess the most affordable and nutritional food to support purchase decisions when both price and healthiness of food are crucial determinants of food choices. Using fuzzy sets to represent healthiness and price of food and the integration of domain expertise with knowledge of socio-economic conditions of the consumer group, allows customizable models matching user requirements. The assumptions made in this study are that the target consumer group does not have any special dietary requirements and health conditions thus only the basic nutrition supply is considered in the study; and the availability of vitamins and other fortified nutrients as well as the Glycaemic Index, were not considered. Wholemeal bread was taken only as an example to demonstrate the application of the proposed methodology which can be extended to check the level of multiple specific nutrients required by the consumer group, optimised together by using the Prerow value. This model can also be extended to include more than two decision variables and can be used for price and nutrition optimised menu planning decisions.

Contributions to Consumer Knowledge

The practical implications of this model are most specifically important for consumer groups who consider the identification of foods with optimum cost and healthiness is crucial. Implementing a systematic method as proposed in this paper enables integrating contextual preferences with the diet and health requirements in a positive manner through open discussions especially when this method is extended for cost and nutrition optimised menu planning. The scalability of the proposed method enables consumers accommodate multiple decision factors including the total healthiness of the product based on individual nutrient levels, product price, specific health requirements of the consumer and also social conditions such as food preferences and beliefs. The benefits of this method for consumers include not only the ability to make straight purchase decisions but also the possibility of identifying food products that will not be considered as obvious purchase options, otherwise. The adoption of fuzzy expert system enables the integration of contextual knowledge and domain expertise in health and diet together to identify and localise the best purchase decisions. This method can be further developed into a software application for ease of adoption by ordinary consumers and to allow them to dynamically check the best foods with price changes or new products coming to the market. In such software applications, the consumer groups should have the flexibility of adapting the fuzzy rule tables to fit the contextual conditions with expert advice. At a macro level, this method is useful for large scale nutrition program implementations such as school canteens, hospitals and elderly homes for selecting cost effective nutritious food products that meet the requirements of the intended consumer community.

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