A Well-Balanced Menu Planning with Fuzzy Weight

Tomoko Kashima, Shimpei Matsumoto and Hiroaki Ishii

Abstract— **For lifestyle-related disease caused by recent change of eating habits in Japan, this paper proposes a menu planning method using rough set theory, and it can satisfy each individual's taste. The menu is made by combining some dishes which are selected by fuzzy mathematical programming problem we introduced. All dishes have meta-information like users' taste, materials, nutritional information, and relativeness (affinity) between some dishes given by an experts (system administrator) of this system, and by using these values as parameters, a well-balanced menu is recommended for each user. This paper assumes that the each individual's taste is as rules obtained by rough set theory.**

Index Terms—**Information System, Fuzzy Mathematical Programming, Lifestyle- Related Disease, Well-Balanced Menu Planning, Rough Set.**

I. Introduction

The Japanese eating habits has drastically changed due to the today's westernization such as the spread of fast-food services and convenient stores. Although it has experienced a sharp downturn in consumption of traditional ingredients in Japanese cooking including rice, the consumption of lipid-rich meals has been rapidly growing. A lot of it is poorly balanced, unhealthy foods, and they have increased the risk of lifestyle-related diseases like obesity and diabetes.

Based on the social backgrounds, we can see that various efforts including industry, government and academia have been undertaken to solve the problem. At first as a representative example of private-sector corporation effort, Ezaki-Glico Co., Ltd., a Japanese confectionery company manufacturing the traditional Glico caramel candy as well as Pocky, has developed a nutrition navigator system on the Web, and been disclosed it without cost [1]. The system provides nutrition information of 1878 common foods based on the standard tables of food composition in Japan (fifth revised and enlarged edition 2005), so by using the system we can precisely measure each nutritional component in real time and without difficulty. However, the system can only add up numerical value of each ingredient due to the simple design, so we cannot make own original menu with nutrition information.

As academic outcomes, Hasegawa, et al. have developed a nutrition management system using camera-equipped cell-phone [2]. With this system, users can get the nutritional advices from dieticians by sending a picture image of everyday meals. The system is of great utility, on the other hand the system requires much running costs including the labor cost of dieticians and the effectiveness might depend on the expert's knowledge. As another instance, Kurashige, et al. have discussed a menu planning by using fuzzy mathematical programming [3]. Their model has planned one menu by considering the nutritional balance and the affinity between some dishes. As usual it is not so easy to match many nutritional components like vitamin, mineral and calcium to the proper nutritional intake with paying attention to the taste and flavor. Then their idea is that each ideal value of nutrition quantity consisted of some ingredients has been expressed as fuzzy number, though usual methods have defined the proper nutritional intake as exact numerical value.

This study addresses well-balanced menu planning problem modeled by fuzzy mathematical programming without expert's knowledge, and aims to obtain efficient menu information quickly and easily not requiring time and expense. From now in menu planning, the user's subjective information such preference, faddiness and habits has not been treated as unimportant, so this paper considers the individual's subjective information as the most important factor, and it is realized by using rough set theory [4-5].

The rough set theory is a formal approximation of a crisp set in terms of a pair of sets which give the lower and the upper approximation of the original set, and recently it has been known as one of the data mining technique because many beneficial fruits have been obtained by previous researches. For example, Enomoto, et al. have discussed about a method of rough set to obtain performance-based decision rules about the audio products design preferred by more consumers [6]. In addition, the rough set has been applied to obtain sensibility for the design about cars and cellular phones. As previous efforts like these, this study assumes that the rough set might be possible to extract the each indivisual's preference rules of foods as well as other researches.

In the traditional rough set, it has been pointed out that when a decision table is with some errors, the lower approximation meets extremely small and precise analysis cannot be conducted. Therefore, this study adds weight to

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express the importance for the decision value of rough set, and the decision values are expressed with the fuzzy number.

II. WELL-BALANCED MENU PLANNING

We make the menu planning which consider of both balance of nutrition and individual's taste. First, we extract rule of individual's taste using rough set in 2-1. Menu database is added information which obtained by rough set. Next 2-2, we make the menu using fuzzy mathematical programming in the menu database of restricted region. The menu is the right kind of menu. The menus combine some dishes. A dish has in-formation of individual's taste and values of some nutrients. The compatibility matrix of each dish is set. We make well balanced menu planning which is considered individual's taste and nutrients.

A. Rule Extraction

In this study, we extract user's taste using rough set. First, we build individualized menu database. In the next menu planning, the menu database is limited search domain. We bring real-time search to realization. It is pointed out by the researcher that lower approximation of usual rough set be-comes extremely-small, and useful analysis cannot be con-ducted. Then, we added to importance of decision value. It is difficult to decide the each importance of right value. We put importance into fuzzy number. For example, one importance of value is 0.85, the other is 0.86. It may become the classification which is completely different with the mere difference in 0.01. We use fuzzy number "approximately 0.85"or "approximately 0.86" in that context.

Table1. Decision Table

U	Q				
	C				D
menu	Protein	Fat	energy	salt	taste
m1	Few	Few	Very high	Lots	Yes
m2	Few	Lots	High	Lots	Yes
m3	Lots	Few	High	Few	No
m4	Lots	Lots	High	Few	Yes
m5	Few	Few	Very high	Lots	No
m6	Lots	Few	Normal	Few	No

First of all, we show the Pawlak's basic model.

$$IS = (U, Q, V, \rho) \tag{1}$$

Target data have some attribute value data. Table1 is showed the attribute values and the decision value. It is called information system. This information system has 4 attribute values and 1 decision value.

where U is the universe which is a non-empty finite set of objects x ; Q is a finite set of attributes q ; $V = U_{q \in Q} V_q$, and V_q is the domain of attribute q ; ρ is a mapping function such that $\rho(x,q) \in V_q$ for every $q \in Q$ and $x \in U$. Q is composed of two parts: a set of condition attributes (C) and a decision attribute (D), i.e., $Q = C \cup D$. Table1 has 6 dishes of data. There are 5 kinds of data which are protein, fat, energy, salt and taste. The value of taste is decision attribute. The values of decision attribute are decided by User. In this table1, $U = \{m1, m2, ..., m6\}$, $C = \{P, F, C, S\}$, $D = \{T\}$, $V =$ {few, lot, yes, no, very high, high, normal}

ρ also is called a decision function. If we introduce function $\rho_x : Q \to V$ such that $\rho_x(q)$ $\rho = \rho(x,q)$ for every $\rho \in Q$ and $x \in U$, ρ_x is called decision rule in IS, and x is called a label of the decision rule ρ_x . Let $IS = (U, Q, V, \rho)$ be an information system, and let $\rho \in Q$, x , $y \in U$. If $\rho_x(q) = \rho_y(q)$, then we say x , y and indistinguishable, in symbols $xR_q y$ where R_q is an equivalence relation. Also, objects x , $y \in U$ are indistinguishable with respect to $P \subset Q$ in IS , in symbols $xR_p y$, if $xR_p y$ for every $p \in P$. In particular, if $P = Q$, x , y are indistinguishable in IS , in symbols xRy instead of $xR_Q y$. Therefore each information system $IS = (U, Q, V, \rho)$ defines uniquely an approximation space $A = (U, R)$, where R is an equivalence relation generated by the information system IS . The equivalence relation R partitions U into a family of disjoint subsets which are called Q -elementary sets. Likewise, R_C leads to C -elementary sets, and R_D leads to D -elementary sets.
Given an arbitrary set $X \subseteq U$, in general it may not be possible to describe X precisely in A . One may characterize X by a pair lower and upper approximations.

Let R be an equivalence relation on a universe U . For any set $X \subset U$, the lower approximation $\underline{apr}(X)$ and the upper approximation $\overline{apr}(X)$ are defined by as follows:

$$\underline{apr}(X) = \{x \in U \mid [x]_R \subseteq X\} \tag{2}$$

$$\overline{apr}(X) = \{x \in U \mid [x]_R \cap X \neq 0\} \tag{3}$$

where

$$[x]_R = \{y \mid xRy\} \tag{4}$$

is the equivalence class containing x .

The lower approximation $\underline{apr}(X)$ is the union of elementary sets which are subsets of X , and the upper approximation $\overline{apr}(X)$ is the union of elementary sets which have a non-empty intersection which have a non-empty intersection with X . The set $bnd(X) = \overline{apr}(X)$ - $\underline{apr}(X)$ is called boundary of X in A . If $bnd(X)$ is empty, then subset X is exactly definable. Note that rough set is a set (pair) of lower and upper approximation.

An accuracy measure of set X in the approximation space $A=(U,R)$ is defined as

$$\alpha(x)=\frac{|\underline{apr}(X)|}{|\overline{apr}(X)|} \tag{5}$$

Clearly, it is true that $0\le\alpha(X)\le1$. Besides, X is called definable in A if $\alpha(X)$ =1, and X is called indefinable in A if $\alpha(X)$ =1, and X is called indefinable in A if $\alpha(X)<1$. Now, let us consider the issue of rule extraction from an information system. A natural way to extract rules, or represent expert's knowledge, is to construct a sets of conditional productions, each of them having the from

IF {set of conditions} THEN {set of decisions}

Such a form can be easily induced by taking the advantage of rough set. In an approximation space $A=(U,R)$, regarding a subset X of U , the whole universe U is partitioned into three regions:

Positive region $pos(X)=\underline{apr}(X)$ (6)

Negative region $neg(X)=U$ - $\overline{apr}(X)$ (7)

Boundary region $bnd(X)=\overline{apr}(X)$ - $\underline{apr}(X)$ (8)

For example, $\underline{apr}(X)$ = {m2, m4}, $\underline{apr}(X)$ = {m1, m3, m5, m6}, $pos(X)$ = {m2, m4}, $neg(X)$ = {m3, m6}, $bnd(X)$ = {m1, m5}.

A universal set can be classified into three fields by rough set. Figure2 shows visually. A universal set can be classified by using a rough set. However, at the time of the classification of a universal set, the importance of each attribute is the same, and importance is not taken into consideration. For example, the menus m1 and m5 of Table 1 are considered. The value of an attribute value, protein, lipid, energy, and salt is the same value. The value of the taste of a decision value is different. Although all attribute values are the same value, a decision value is different. Menus A and B are classified into upper approximation and a boundary region. Therefore, we take importance into consideration to a decision value.

Next, we show rough set using fuzzy in this study.

$$USI=(U,C,D,V,\rho,\widetilde{W}) \tag{9}$$

where U is the universe which is a non-empty finite set of objects x; C is a finite condition set of attributes; D is a finite decision set of attributes; $V=\cup_{q\in C\cup D}V_q$, and V_q is the domain of attribute q; ρ is a mapping function such that $\rho(x,q)\in V_q$ for every $q\in C\cup D$ and $x\in U$; $\widetilde{W}=\cup_{x\in U}\widetilde{\omega_x}$, and $\widetilde{\omega}_x$ is a fuzzy number defined by membership function $\mu_{\tilde{w}_x}$ $\rightarrow$ [0, 1], which assigns each tuple an importance (weight) factor to represent how important (weighty) is for the corresponding decision.

Let E , X be a non-empty elementary set, and a non-empty subset in the approximation space, respectively. It is defined a concept which is called relative degree of classification of the set E with respect to set X as follows:

$$\tilde{c}(E,X)=\frac{\sum_{x\in I}\tilde{w}_x}{\sum_{x\in E}\tilde{w}_x} \tag{10}$$

$$I=E\cap X \tag{11}$$

Show bout set X in figure1.

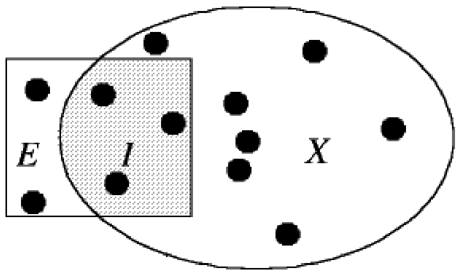

Figure1 : E , X , and their intersection I

Two thresholds $\tilde{\beta}_P$, $\tilde{\beta}_N$, which are called positive threshold, negative threshold, respectively. We say that E is included in X , if $\tilde{c}(E,X)\ge\tilde{\beta}_P$, and E is connected nothing with X , if $\tilde{c}(E,X)\le\tilde{\beta}_N$. Based on the relative degree of classification (3), the lower approximation, and upper approximation of a subset X with respect to thresholds $\tilde{\beta}_P$ and $\tilde{\beta}_N$, in symbols $\underline{apr}_{\tilde{\beta}P}(X)$, $\overline{apr}_{\tilde{\beta}N}(X)$ respectively, are defined as

$$\underline{apr}_{\tilde{\beta}r}(X)=POS_{\tilde{\beta}P}(x) \tag{12}$$

$$\overline{apr}_{\tilde{\beta}N}(X)=U-NEG_{\tilde{\beta}N}(x) \tag{13}$$

where,

$$POS_{\tilde{\beta}P}(x)=\bigcup\{E\in R_C^*\mid\tilde{c}(E,X)\ge\tilde{\beta}_P\} \tag{14}$$

$$NEG_{\tilde{\beta}N}(X)=\bigcup\{E\in R_C^*\mid\tilde{c}(E,X)\le\tilde{\beta}_N\} \tag{15}$$

$$BND_{\tilde{\beta}P,\tilde{\beta}N}(X)=\bigcup\{E\in R_C^*\mid\tilde{c}(E,X)\ge\tilde{\beta}_P,\} \tag{16}$$

In this way, the accuracy measure of set X in the approximation space A = (U, R) is given by

$$\tilde{\alpha}(x)=\frac{\sum_{x\in\underline{apr}\tilde{\beta}P}\tilde{w}_x}{\sum_{x\in\overline{apr}\tilde{\beta}N}\tilde{w}_x} \tag{17}$$

Example, there is an information system. It is a database about a user's menu. The menus have user's favorites (Table 2). There are 6 menus. And there are three attributes of a menu.

Table2. Dishes and individual's taste

	C			D
U	a1	a2	a3	favorite
m1	1	1	1	0($\widetilde{1.0}$)
m2	1	2	1	1($\widetilde{0.2}$)
m3	2	2	2	1($\widetilde{0.1}$)
m4	2	1	2	0($\widetilde{0.6}$)
m5	2	2	2	1($\widetilde{0.4}$)
m6	1	2	1	0($\widetilde{0.8}$)

Table3. Numeric expressed of attributes value.

	Attribute	0	1	2	3
a1	Kind of cooking	Japanese	European	Chinese	other
a2	Main materials	Meat	Fish	vegetable	other
a3	Cooking method	Boil	Burn	Frit	other

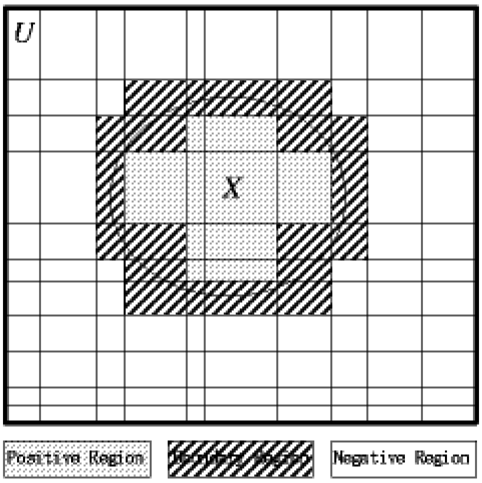

Figure2 : Traditional POS Region, NEG Region, BND Region

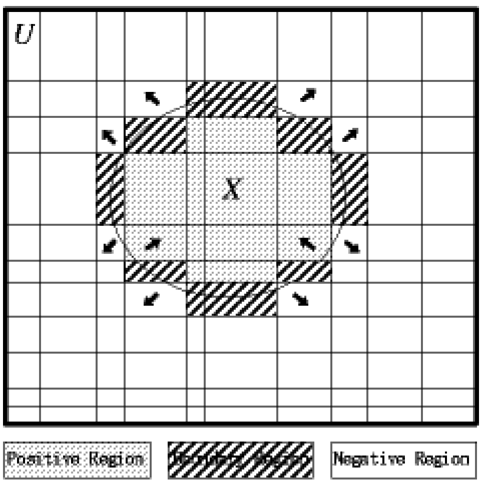

Figure3 : Considered Importance of POS Region, NEG Region, BND Region

In the information system, U = {m1, m2, …, m8} in which each element expresses a menu. A meal is classified with attributes. Attribute set = {a1, a2, a3}. The value of attribute values and a determination values are numerically expressed, in order to make it intelligible (Table3). Symbol 'a1' expresses the kind of cooking. Japanese-style food is 0, European food is 1, and Chinese food is 2. a2 classifies the main materials. Meat is 0, fish is 1, and vegetable is 2. a3 classifies the cooking method. Boil is 0, burn is 1 and frit is 2. Others are 3 in all the items.

Sets of equivalence are as follows.

{{m1}, {m2, m6}, {m3, m5}}

$$\underline{apr}_{\tilde{\beta}P}(X) = \{m3, m5\} \quad (18)$$

$$\overline{apr}_{\tilde{\beta}N}(X) = \{m2, m3, m5, m6\} \quad (19)$$

Lower approximation {m3 and m5} expresses that it is the set with the information on the element which is completely a user's luxury goods. Upper approximation {m2, m3, m5, and m6} expresses the set of the object which cannot be definitely said unless it is a user's luxury goods using the information about an attribute set. Therefore, it becomes possible by taking in the information on lower approximation and upper approximation to select the menu which suited the user's taste. On the contrary, it is not suitable for a user's taste to come out other than this and to take in the menu of a certain negative region. Therefore, in a menu plan, solution search space is limited with a right region and a boundary region.

B. Menu Planning

Menu planning aims at the proposal of the right kind of menu. First, we set up maximum and minimum values of object function in the restricted domain given by 2-1. User set up maximum and minimum number of each genre of menu here. Next, membership functions to each object functions are decided. The membership functions are indicated by figure4-figure7. Next, User picks a dish that would like to be considered in the menu. The selected single dish becomes a set of a menu candidate's single menu today. So a menu is created by solved the combination of a single dish using mathematical plan problem. We refer to menu planning using fuzzy mathematical plan problem. When taking into consideration two or more nutritional balance, it is difficult to make it in agreement with a desired value. Therefore, the required amount of nutrition is expressed with the fuzzy number which can express ambiguity. Let the value of the membership function about each nutrient be a vague value. A mathematical plan problem is formulized as follows.

n	: number of dishes	$(1 \le i, j \le n)$
m	: number of nutrients	$(1 \le k \le m)$
h	: number of groups	$(1 \le h \le H)$
X	: set of dishes	$x_i \in X'$ $x_i \in POS_{\tilde{\beta}P}(x)$

X' : menu candidate who wants to eat (set of dish) $(X' \in X)$

x_i : If dish i is added for a menu, decision value will be 1. If dish i is not added for a menu, decision value will be 0.

M_{ij} : If compatibility between dish i and dish j is good, Value is 0. If compatibility between dish i and dish j is bad, Value is 1,

Q_{ik} : amount of nutrient k in dish i

N_k : as shown in the following equation of amount of nutritional k

$$N_k = \sum_{i=1}^{R} x_i . Q_{ik}$$

$f_k(N_k)$: membership value of nutritional intake N_k for nutritional k

L_h : minimum value of group h

U_h : maximum value of group h

$$\text{maximize} \quad \min_{k} f_k(N_k) \qquad k = 1, 2, ..., m \tag{20}$$

$$\text{subject to} \quad 0 \le \lambda \le 1 \tag{21}$$

$$\lambda \le f_k(N_k) \tag{22}$$

$$\prod_{i=2}^{R} \prod_{j=1}^{i} \frac{4 - M_{i,j}(x_i + x_j)\left\{1 + (-1)^{(x_i + x_j)}\right\}}{4} = 1 \tag{23}$$

$$L_h \le \sum_{i=1}^{N} x_i . B_{ih} \le U_h \tag{24}$$

The mathematical formulations are expressed.

$$\text{maximize} \quad \lambda \tag{25}$$

$$\text{subject to} \quad 0 \le \lambda \le 1 \tag{26}$$

$$\lambda \le f_k(N_k) \tag{27}$$

$$\prod_{i=2}^{R} \prod_{j=1}^{i} \frac{4 - M_{i,j}(x_i + x_j)\left\{1 + (-1)^{(x_i + x_j)}\right\}}{4} = 1 \tag{28}$$

$$L_h \le \sum_{i=1}^{N} x_i . B_{ih} \le U_h \tag{29}$$

The balance of the whole nutrient is taken into consideration. Therefore, objective function is shown making maximization of a membership function value. Let the membership function value be a nutrient with the lowest evaluation (25). The balance of the whole nutrient is taken into consideration. Therefore, objective function is shown making maximization of a membership function value. Let the membership function value be a nutrient with the lowest evaluation. It is shown that all the compatibility of each dishes are good combination (28). It will be set to $M_{ij} = 0$ if the compatibility of the selected dish is good. Therefore, it is certainly set to 1. It is taking into consideration that it is within a defined area of the number of cooking belonging to each group (29).

The membership function to each nutrient is shown in Figures 4-7. The amount of nutrition needed is shown in Table 4.

III. RESULTS

The number of cooking is 150. Groups are staple (rice), staple (noodles), staple (baked), soup, main dish, and side dish. A dish to eat has no specification. The affinity matrix of each single dish is a random value. It calculated using the genetic algorithm. The selected dishes are green stems of fresh garlic, saute of white meat, chicken with rice and miso soup of radish.

Table4 .Set value of group

Group	Maximum	Minimum
Staple(rice)	1	1
Staple(noodles)	0	0
Staple(baked)	0	0
Soup	1	1
Main dish	3	1
Side dish	1	0

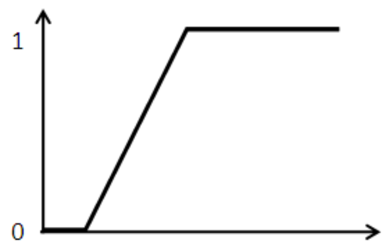

Figure 4.The membership function of energy and protein

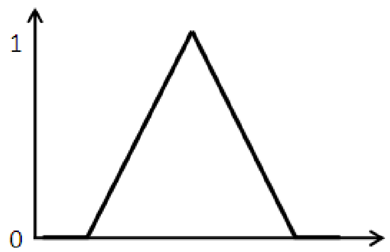

Figure 5.The membership function of a dietary fiber

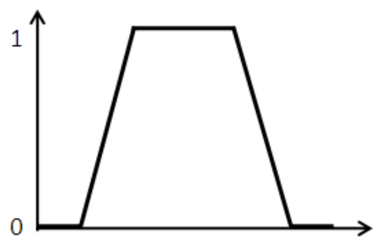

Figure6.The membership function of lipid and carbohydrate

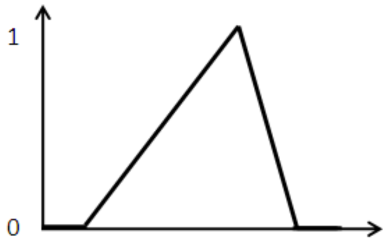

Figure 7.The membership function of salt

Table 4.The amount of nutrition

Nutrient	Below tolerance level	Fiducial point	More than tolerance level
Energy	558.6	610.9	663.3
Lipid	13.6	-	20.4
Dietary fiber	4.3	5.3	-
Protein	12.5	13.7	122.2
Carbohydrate	76.4	-	106.9
Salt	0	2.7	-

Table 5.Intake Estimation of nutrient

Nutrient	Intake Estimation
Energy	625.37
Lipid	21.39
Dietary fiber	6.34
Protein	29.86
Carbohydrate	75.50
Salt	10.82

IV. CONCLUSION

In this research, we created the menu database in consideration of user's taste using defined new rough set. Moreover, in order to take the nutrient of a menu into consideration, the menu creation plan using fuzzy mathematical programming was remarked. Further research, the development using multiobjective clustering of food, set covering, etc. is considered.

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