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OPTIMIZATION OF THE MENU FOR INSTITUTIONS OF RESTAURANT INDUSTRY BASED ON MATHEMATICAL MODELLING METHODS

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Abstract: *This study is dedicated to innovative approaches to the individualization of service in institutions in the restaurant industry based on the requirements of balanced nutrition and cost optimization. The study was conducted on the materials of the existing objects of the restaurant industry in Kyiv (Ukraine), taking into account the approved norms of the energy value of the daily diet for different age groups. The solving of the problem was carried out by linear programming methods on the example of a specific category of consumers: men aged 18–29 years old. The coefficient of physical activity was set at 1.4, with which the optimization task of compiling menus from Ukrainian and Georgian cuisine was formulated. The prices of famous Kiev restaurants, the content of nutrients and energy values of dishes, and the nutrient consumption rates were established for the selected category of customers and used as the initial data. It is demonstrated that the condition for minimization of the target function (account) allows for a reduction in the cost of nutrition by up to 20%, without reducing energy value and nutrition.*

Substantiated proposals in the study for the compilation of an individual menu can be the basis for the diversification of restaurant services and increase the competitiveness of the enterprises in the industry, as they take into account the current trends in nutrition and the requirements of the organization for useful and controlled nutrition with restrictions on the content of energy and useful substances, whilst also minimizing the cost of the check. They can be implemented in restaurant establishments in the form of the introduction of an additional module in widespread information and payment systems (Fidello F&B, Micros, "Parus-Restaurant," SERVIO, 1C-Rarus: Restaurant + Bar + Cafe, Iiko, R-keeper, others.).

Keywords: *Restaurant management, menu customization, balanced eating, check minimization, linear programming, optimization.*

JEL: *L60, L66.*

1. Introduction

Increasing competition among establishments in the restaurant industry requires the orientation of enterprises towards maximizing the consideration of current trends in healthy eating, and the fulfilment of the wishes of target groups of consumers and the individual requests of visitors. The success of the restaurant business involves a creative approach to its organization, the maximum use of the facilities of the institution, and the introduction of additional channels of communication with customers. An individual approach to each client, taking into account their culinary and gastronomic preferences, becomes one of the main modern trends in the organization of catering.

There will come a time when restaurant customers will not only be able to choose dishes at their own discretion, but also to shape them independently, taking into account the peculiarities of their diet and personal tastes. In this case, individual nutrition can vary for a number of reasons, including: diets for medical indications; vegetarianism; the nationality or age of consumers; raw food diet; Ayurvedic nutrition; Fruitarianism, etc. However, any choice of nutrition should ensure a balanced consumption of energy, protein, carbohydrates, fats, vitamins, and micro-elements, taking into account the daily physiological needs of a particular person in terms of nutrients.

2. Literature review

A considerable amount of work both by international and Ukrainian researchers is devoted to determining balance in human nutrition and the factors that influence this indicator. Scientists have proposed various algorithms for the development of recipes in order to obtain the optimal ingredient composition of meals.

The normal physical needs for nutrients and energy of different population groups and reference materials characterizing the energy value of foodstuffs and their chemical composition are taken into account [2]. The importance and complexity of nutrient balance selection, depending on the tasks assigned to a particular group of consumers, is

emphasized, and balanced nutrition is associated with both personal human needs and the concentration of nutrients in foods [3].

The global introduction of mobile and online technology into the restaurant business contributes to the organization of the broadcasting by consumers of their gastronomic preferences to food companies, and aids their managers in fixing and maintaining the wishes of their regular customers. The ability to order food online, free Wi-Fi in establishments, the presence of an electronic menu – these are already common catering services for visitors. Modern restaurant information systems allow businesses to analyze the dynamics of sales to further predict them and, accordingly, to prepare a procurement plan and work schedules for line staff.

One of the technologies of restaurant service is related to the availability of terminals or tablets that include the menu at every restaurant table. This service allows customers to order meals without waiting for the waiter, make changes to the order, and visualize the meal and its value. This paper proposes the use of these technologies to make an individual menu with a specific content of energy, nutrients, micro-elements, or vitamins. The mathematical programming methods used to solve this problem are widely used in dietetics.

Already in the first publications on this topic [4; 5] we discussed the practical applications of the solution to the problem of producing the optimal diet. A review of scientific works devoted to the use of linear programming in the optimization of nutrition and compiling diets, taking into account certain limitations, was provided in the article [6]. In particular, attention was drawn to the considerable potential of linear programming techniques for finding solutions to various nutrition problems.

The works of French researchers such as Briend, Darmon, Ferguson, and Erhardt [7] emphasized that linear programming is "the ideal tool for rigorously converting precise nutrient constraints into food combinations." The studies of Dutch scientists such as van Dooren, Tyszler, Kramer, and Aiking [8], taking into account low food costs, include restrictions on the emissions of greenhouse gases into the atmosphere that accompany the cultivation of certain foods.

The research of such scholars as Parlesak et al. [9] are dedicated to the creation of low-cost consumer product baskets that take into account nutrient recommendations, dietary recommendations, and cultural acceptance. Linear programming methods were also used.

There are works, particularly those of Ukrainian scientists such as Liashenko and Shulak [10], where different approaches to the design of information subsystems for determining a balanced diet are offered.

Mathematical methods of designing diets with certain conditions on the content of ingredients are used by the Kharkov scientists Cherevko, Krutovyi, and others [11–15].

Research in the field of biotechnology also suggests the use of computer technology – for example, recipe optimization tasks can be used to develop a functional product. In this case, the formulation of the problem introduces criteria for minimizing deviations from the specified content of nutritional and biological indicators [16].

Firstly, however, we must consider that even the modern development of information systems for restaurants does not pay due attention to the interests of the customer, i.e., a focus on healthy and controlled nutrition [17]. Secondly, scientific research on nutrition optimization is mainly focused on the preparation of diets for therapeutic or

therapeutic prophylactic action. In addition, quite often the word "optimization" is used in a more general sense rather than in terms of optimization by mathematical programming methods. Finally, even in studies that are devoted to finding the best diet with the goal of minimizing its cost, a set of specific foods, not meals, is meant.

3. Purpose

The purpose of this study is to develop proposals that combine the efforts of food establishments to diversify their services, the capabilities of mathematics and information technologies, and current customer requirements for balanced and healthy eating.

The problem of the optimal cost of food and the minimization of the check in the restaurant establishment without a reduction in the daily physiological norm of energy exchange is also urgent, taking into account the realities of our country. The limitations of the linear programming problem are then related to the consumption of energy, nutrients, minerals, and vitamins, and the intended result is hindered by the cost of the check.

Accordingly, another objective of the study was to improve the service process in restaurant establishments by introducing a menu-based service that helps customers to consume nutrients and minimize cost.

4. Methods

The methods of analysis and synthesis, statistical comparisons, and the grouping and generalization of scientific data on the energy values of the products of restaurants in Ukrainian and Georgian cuisine and their cost as of April 1, 2020, were used in the study of the optimization of the process of providing food services in institutions of the restaurant industry. Linear programming methods, Excel spreadsheets, and the "Solution Search" superstructure were used to solve the research objectives.

5. Results

The development of an adequate diet is quite a challenge, the solution to which depends upon many factors. The value of energy metabolism is an indicator of the general state and physical activity of the body. The level of daily energy consumption of a person depends on sex, age, height, size of the surface area of the body, constitution, health status, intensity and duration of muscular activity, nature of nutrition, climate, meteorological factors, season of the year, and time of day. Therefore, the standard, and at first glance quite simple, problem of linear programming regarding the diet becomes the task of finding a solution without many restrictions, which often contradict each other. The economic and mathematical model of the problem is: to determine such integral values of x_1, x_2, x_3, ... x_n, at which the objective function reaches a minimum (minimization of the cost of nutrition or content in the diet of a certain substance).

$$S=c_1x_1+c_2x_2+c_3x_3+\ldots c_nx_n \rightarrow min$$

і виконуються обмеження

$$\begin{cases} a_{11}x_1+a_{21}x_2+a_{31}x_3+\ldots a_{n1}x_n \geq b_1 \\ a_{21}x_1+a_{22}x_2+a_{32}x_3+\ldots a_{n2}x_n \geq b_2 \\ a_{13}x_1+a_{23}x_2+a_{33}x_3+\ldots a_{n3}x_n \geq b_3 \\ - - - - - - - - - - - - - - - \\ a_{1m}x_1+a_{2m}x_2+a_{3m}x_3+\ldots a_{nm}x_n \geq b_m. \end{cases}$$

Typically, in studies using this model, the mix problem, the variables $X(x_1, x_2,\ldots.x_n)$ are ingredients in the formulation of certain dishes, foods in the diet of daily or single consumption, components of a "grocery basket," or food additives. In this work, it is suggested to use a set of dishes from the menu of a particular establishment as variables.

The coefficients $c_1,c_2,\ldots.c_n$ of the objective function of the problem are prices. In this case, the price of the dishes is included into the restaurant menu.

The limitations of the task can be formulated as inequalities with the signs >=, <=, or equality = depending on their content. Thus, for example, the range is indicated within which it is permissible to adjust the content of nutrients.

Coefficients $a_{11}, a_{12},\ldots..a_{mn}$ in the restriction system are the content of nutrients, energy, minerals, or vitamins in a particular dish. That is, the meaning of the coefficients in the system of inequalities can change depending on the task that is being set. Accordingly, the interpretation of the right-hand side of inequalities $b_1,b_2,\ldots.b_m$, may be different – namely, they may be restrictions on the consumption of energy, fats, proteins, carbohydrates, different minerals, and vitamins. In addition, weight restrictions on some dishes from the catering menu can be placed on the right side.

The initial data for obtaining the optimal admissible plan $X(x_1, x_2,\ldots.x_n)$ in the solution of the problem are: nutrient and energy consumption rates for a certain category of population, component prices (in our case, prices of meals in the institution's menu), and the composition of substances in components (in our case in every dish). The source of energy for the body is nutrients. There are many tables of average energy consumption for various activities that can be used to determine daily energy costs [18]. It is possible to calculate the daily need for basic nutrients and biologically active substances (proteins, fats, carbohydrates, vitamins, minerals) on the basis of the obtained value of the average energy consumption. The norms of consumption of basic nutrients by the population of Ukraine are determined depending on sex, age, and physical activity, approved by the order of the Ministry of Health of Ukraine of September 3, 2017, No. 1073 "On approval of the Norms of physiological needs of the population of Ukraine in basic nutrients and energy" [1].

This paper proposes the use of linear programming methods to obtain the optimal composition of meals from the menu of a particular institution. The first stage of this task is the formation of a template with the specified parameters of the target function, and the constraint system is solved with the help of Excel spreadsheets and the "Search for Solution" superstructure. As an example, a category of consumers was selected which could include students, young teachers, office workers without significant physical activity, and

foreign and domestic tourists – namely, men aged 18–29 years. According to the MOH order above, the daily requirement of this population in proteins, fats and carbohydrates, minerals, and vitamins is shown in Table 1.

Table 1. *Daily requirements of men (18–29 years) for energy, essential nutrients, and biologically active substances*

Group	Group The coefficient of physical activity (hereinafter – CFA) (D) Carbohydrates (D)	Energy (Kcal)	Proteins (g)		Fats (g)	Carbohydrates (G)
			everything	including animals		
I	1.4	2450	80	40	81	350
II	1.6	2800	91	45	93	400
III	1.9	3300	106	52	107	478
IV	2.2	3900	108	54	128	566
V	2.5	4100	117	58.5	154	586

Minerals								
Group	Calcium (mg)	Phosp-horus (mg)	Magnesium (mg)	Iron (mg)	Zinc (mg)	Iodine (mg)	Copper (mg)	Chrome (mcg)
I-V	1200	1200	400	15	15	150	1.0	50
Vitamins								
Group	C (мг)	A (mcg PE)	E (mg TE)	D (μg)	B_1 (mg)	B_2 (mg)	B_6 (mg)	K (μg)
I-V	80	1000	15	5	1.6	2,0	2.0	110

Source: Based on [1]

The specific indications of the units of daily requirement for vitamins, which are presented in the table, are related to the use of coefficients for the conversion of various forms of vitamin preparations. For example, vitamin A (mcg PE) is in retinol equivalent. These details are not relevant to the topic of this work and are related to the biological activity of vitamins, the study of which is engaged in vitaminology.

It should be emphasized that, for various reasons, producing an optimal diet is a difficult task and often has several options. Therefore, at the same time, to take into account the consumption of energy, fats, proteins, carbohydrates, essential micro-elements, and vitamins when solving one optimization problem is almost impossible. Additional factors that complicate this task are:

– the content of nutrients and energy in the same dish may vary, albeit slightly, depending on the quality of the ingredients or the characteristics of the preparation;

- the individual wishes of the client require additional restrictions on the presence or absence of a particular dish;

- the number of dishes offered for selection may also vary depending on the individual needs of the consumer (diet, religious beliefs, current health, etc.);
- the requirements of the consumer when forming the order (collective, individual, festive, every day, etc.)
- the type and peculiarities of business process organization in restaurant establishment.

Therefore, the limitations of the task should be less severe to allow the consumption of a substance or energy within a certain interval. The presence of an optimization task template makes it easy to change both the nomenclature of dishes and their number, as well as to adjust the rates of consumption of nutrients and energy, depending on the characteristics of the consumer (gender, age, physical activity etc.).

Therefore, the development of daily menu options for men aged 18–29 years, optimized by minimizing the cost of the check and taking into account restrictions on energy, fat, protein, and carbohydrate consumption, is proposed in this this paper. Assuming that the customer pays at each visit to the restaurant (not necessarily the hotel structure), the daily menu was divided into three parts: breakfast, lunch, and dinner. According to common recommendations, for 3 meals a day, the ratio of energy and nutrients should be as follows: 30% – 40% – 30%. It is also extremely difficult to implement this.

The national variety of cuisines offered at Kyiv food companies can satisfy almost any taste. The menu of the Ukrainian cuisine restaurant "Ukrainian dishes" was chosen for the following reasons:

- it presents the national cuisine;
- it has a fairly diverse menu;
- it is actively visited by foreign tourists;
- its menu and prices are calculated for average consumers;
- its menu does not indicate the content of nutrients and energy.

The solution to the task of preparing a breakfast menu of dishes from Ukrainian cuisine with a minimum cost for the specified institution and with a certain content of proteins, fats, carbohydrates, and energy is presented in the Table 2.

Table 2 includes:

- the names of the dishes, taken from the menu offered for selection in the establishment;
- the prices from the menu, scaled up to 1 kg of food;
- the content of nutrients and energy, scaled up to 1 kg of each dish;
- the intervals of restrictions on the content of nutrients and energy (the right part of the restrictions);
- the actual content of nutrients and energy (the left part of the restrictions);
- additional restrictions on the presence of a particular dish among the favourites;
- cells with search results, namely the weight of foods recommended for consumption and the total cost, are highlighted.

Table 2. *The optimized version of the breakfast menu at the restaurant "Ukrainian dishes" for consumers of the selected category*

	Oatmeal porridge with nuts and honey	Scrambled eggs with bacon	Pancakes with sour cream and jam	The omelette is natural	Bread	Tea	Pancakes with Cheese	Coffee with Milk	Cheesecakes			
	X1	X2	X4	X5	X6	X7	X8	X9	X10	Cost, UAH		
Food weight, kg	**0.20**	0	**0.12**	0	0	0	0	**0.20**	0	**105.84**		
Prices (UAH / kg)	190	367	482	312	75	40	505	50	680			
LIMITATION										Left part	Sign	Right part
Proteins	46	102	120	122	55	0	110	15	130	26.60	>=	20
Fat	47	275	75	184	10	0	43	18	194	22.00	>=	22
Carbohydrates	263	6	300	19	400	80	279	100	196	108.60	>=	90
Energy	1480	2130	2600	2220	1900	310	1950	500	3002	708.00	>=	700
Proteins	46	102	120	122	55	0	110	15	130	26.60	<=	27
Fat	47	275	75	184	10	0	43	18	194	22.00	<=	27
Carbohydrates	263	6	300	19	400	80	279	100	196	108.60	<=	110
Energy	1480	2130	2600	2220	1900	310	1950	500	3002	708.00	<=	1000
Bread	0	0	0	0	1	0	0	0	0	0.00	=	0
Pancakes	0	0	1	0	0	0	0	0	0	0.12	>=	0.12

Source: Authors' calculation

Similarly, the task of compiling an optimal Ukrainian lunch and dinner menu for the selected consumer category was prepared and solved (Table 3).

Thus, consumption rates are exceeded by all indicators (energy, protein, fats, and carbohydrates); the main excess was consumed during lunch.

Table 3. *Calculation of the amount of energy, proteins, fats, and carbohydrates in the Ukrainian version of the menu of consumers of the selected category*

Men, 18–29 years old, KFA 1.4	Energy (kcal)	Proteins (g)	Fat (g)	Carbohydrates (g)
Norms	2450	80	81	350
Breakfast	708	26.6	22	196
Lunch	1182	44	54	129
Dinner	797.2	21	31.6	65.9
Realistically applied	2687.2	91.6	107.6	390.9
Difference	237.2	11.6	26.6	40.9
Difference, %	9.68%	14.50%	32.84%	11.69%

Source: Authors' calculation

The largest excess is in terms of fats. Accordingly, there can be two recommendations:

- to increase the coefficient of physical activity;
- to reduce energy, protein, fat, and carbohydrate intake in the coming days.

In recent years, many food establishments have opened in Ukraine, and in particular in Kyiv, offering Georgian cuisine. Among them are highly professional specialists – Georgians, whose cuisine is popular with both Ukrainians and foreign tourists. Therefore, it was decided as a second example to use the menu from the Georgian restaurant "Gogi," in Kiev. Accordingly, the names of the dishes and their prices were taken from the menu of this restaurant. The results of solving the problem of optimizing the breakfast menu with minimal cost and restrictions on the protein, fat, carbohydrate, and energy content are presented in the Table 4.

Table 4. *The optimized version of the breakfast menu for consumers of the restaurant "Gogi" of the selected category*

	Khachapuri	Ajaxon Dali	Dolma	Lobio	Kubdari	Tea	Coffee with Milk			
	X1	X2	X4	X5	X6	X7	X8		Cost, UAH	
Food weight, kg	**0.21**	0	0	**0.12**	0	0	**0.15**		**148.36**	
Prices (UAH / kg)	320	360	547	316	335	82	280			
LIMITATION								Left part	Sign	Right part
Proteins	122.3	75	80	53	78	0	15	34.74	>=	25
Fat	111	67	200	5	106	0	18	27.00	>=	22
Carbohydrates	276.3	82	110	133	270	80	100	90.00	>=	90
Energy	2590	1230	2560	800	2340	310	500	724.26	>=	600
Proteins	122.3	75	80	53	78	0	15	34.74	<=	35
Fat	111	67	200	5	106	0	18	27.00	<=	27
Carbohydrates	276.3	82	110	133	270	80	100	90.00	<=	110
Energy	2590	1230	2560	800	2340	310	500	724.26	<=	800
Kubdari	0	0	0	0	1	0	0	0.00	=	0

Source: Authors' calculation

According to the results of the Georgian version of the menu for men aged 18–29 years with a coefficient of physical activity of 1.4, we calculate the total amount of nutrients (proteins, fats, and carbohydrates) and energy consumed during the day (Table 5).

Table 5. *Calculation of the amount of energy, proteins, fats, and carbohydrates in the Georgian version of the menu of consumers of the selected category*

Men, 18–29 years old, KFA 1.4	Energy (kcal)	Proteins (g)	Fat (g)	Carbohydrates (g)
Norms	2450	80	81	350
Breakfast	724	34,74	27	90
Lunch	1257,4	52,7	53,2	133,25
Dinner	613,5	16,2	11,31	100
Realistically applied	2594,9	103,64	91,51	323,25
Difference	144,9	23,64	10,51	–26,75
Difference, %	5,91%	29,55%	12,98%	–7,64%

Source: Authors' calculation

Thus, exceeding the norms of consumption of nutrients and energy is accomplished by the following indicators: energy – by 5.91%; proteins – almost 30%; fat – almost 13%. The intake of carbohydrates is 7.64% below the norm.

A significant exaggeration of the norms of protein consumption is related to the specificity of Georgian cuisine – namely, a large number of meat dishes.

By giving the customer an invoice, the restaurant informs them only of the amount of money spent. If, at the same time, energy, fats, proteins and carbohydrates consumed during the diet were included in the bill, subsequent meals may be adjusted.

We emphasize that dieting is a rather difficult task, the peculiarities of which are conditioned not only by the basic principles of rational nutrition, but also by the characteristics of each person in a certain population group – not only by age and gender, working and living conditions, but also by health, deviations in the mode of life, and other reasons. Therefore, even the norms of the use of nutrients and energy differ according to various researchers. If, after drawing up a daily diet and calculating its chemical composition for proteins, fats, and carbohydrates, the obtained results deviate from the normative by more than 5%, then the diet is considered insufficiently balanced and the meals included in the menu should be revisited.

The effectiveness of including the cost minimization condition can be estimated by comparing the total checks received with the lowest possible score, and without taking into account this condition (Table 6).

Table 6. *Efficiency of optimization of a diet on condition of minimization of cost*

	Ukrainian cuisine restaurant check		Georgian cuisine restaurant check	
	min	max	min	max
Breakfast	105.84	109.32	148.36	164.96
Lunch	205.75	213.1	234.36	281.35
Dinner	135	137.02	248.98	319.24
Total	446.59	459.44	631.7	765.55
Cost increase		3%		21%

Source: Authors' calculation

It should be noted that some well-known restaurant companies operating in Ukraine are already paying attention to the need for energy balance when choosing an order, by giving information about the energy and nutritional value of dishes on the menu. At the website of the restaurant chain "Puzata Hata," one can find information about the energy, protein, fat, and carbohydrate content of the dish that the customer chooses. The restaurant chain "McDonalds" places this information not only on their website, but also in print promotional items and in fiscal checks.

The authors suggestions for the development of templates for finding the optimal content and energy of a menu, while minimizing its cost, can be used to improve and individualize the services of restaurants, the development of complex menus for individual visitors and organized contingents of consumers, and the development of an additional module of information systems at the enterprise providing food services.

It should be noted that the specialized information systems used in the institutions of the restaurant industry can significantly simplify and accelerate all business processes, in particular by determining the cost of ingredients for each dish, calculating the required number and cost of restaurant products, and creating a menu for the dining hall and the bar price list. Due to the introduction of additional modules in the software systems, the formation of individual checks is simplified, taking into account certain criteria.

For the functioning of a module that implements this method of offering a menu, only information about the available energy value of dishes is sufficient, that is, sufficient access to the database in which this information is available is required. Therefore, this module can be implemented in several variants.

1. The implementation of this module can be implemented as an additional one in the relevant software system (Fidello F&B, Micros, Software complex "Parus-Restaurant," software complex SERVIO, 1C-Rarus: Restaurant + Bar + Cafe, software complex Iiko, R-keeper and others). This module can extend the functionality of existing programs and allow restaurants to offer menus according to the specified criteria.
2. This module can also be implemented as a separate program that uses data from an existing database, and that uses the appropriate program to select menus with the corresponding energy value.
3. It can be implemented in the form of a web-application, which will allow it to be integrated into the website of the respective catering facility, and provide the possibility of selecting menus from the available dishes based on the set criteria.
4. The implementation of the module in the form of a Telegram bot is promising. Telegram provides an open ARI for developing custom versions of bots. This implementation option will allow for a restricted Internet connection by sending a request to get a response – a menu.

6. Conclusions

This article proposes templates for solving the task of optimizing the menu of a restaurant establishment with restrictions on the content of energy and useful substances, and minimizing the cost of the check. The possibility of changing the initial data in ac-

cordance with the individual requirements of the consumer and the features of the food enterprise is substantiated.

The approaches explored in the article can be extended for different categories of consumers and implemented in restaurants of different types of service in order to organize a balanced healthy diet, maintaining regular customers and the aiding the formation of a highly competitive position.

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