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THEORETICAL ASPECTS OF A DECISION-MAKING PROCESS WITH EXAMPLES OF SITUATIONAL PROBLEMS FOR STUDENTS OF MEDICAL UNIVERSITIES

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Having subject to own professional peculiarities every specialist in a varying degree meets the difficulties of decision making. However there are few fields for human activity where it is possible to apply decision making process as ordinary and basic professional skill. Medical activity being sequence of diagnosing and treatment is the typical representative of such a field. Methods of decision making are multipurpose and universal though their successful application substantially depends on professional qualification of the specialist who must have exact understanding of peculiarities of the system he studies and must know how to lay down the task. Department of Medical and Biological Physics and Medical Informatics at Kharkov National Medical University with support of Department of Biomedical Engineering of Kharkiv National University of Radio Electronics have developed and implemented the lecture and practical lesson «Decision making in medicine». It is argued by fact that the doctor meets the common problem in different medical tasks (patient data acquisition, diagnostics, and treatment tactics).

The purpose of the introduction of this topic is to find out the possibility of students mastering various specialties of questions regarding the practical application of elements of decision theory in professional practice. During the practical training, students receive initial data, perform analysis, and identify risk factors and disease factors. On the basis of this information, students formulate many alternatives, then choose the appropriate method of finding the optimal solution and apply the method to the diagnostic or therapeutic process.

This technique has been practiced in the classroom using situational tasks. Not only Ukrainian but also foreign students took part in the classes, who appreciated their performance. The technique aroused very lively interest and continued discussion.

Keywords: *decision-making process, education, medical informatics, Bayes's theorem.*

Various methods like mathematical modeling or management in decision making are used for solving various types of problems to enhance the human ability to make justified, effective decisions.

Modeling methods are based on mathematical models to solve the most frequent management problems, in particular, those in medical field [3]. One of the most common classes of mathematical models are game theory models.

All the requirements formulated in real tasks and written down as mathematical expressions make up so-called the mathematical task definition. The process of the mathematical task definition and its further solution can be presented by following stages [2].

1. The study of an object represents the analysis of object functioning peculiarities. At this stage factors which influence an object are revealed and the level of their influence is defined; object characteristics are studied out under different conditions; optimizing criteria (objective functions) must be chosen.

2. Descriptive modeling lies in setting and fixation of basic connections and dependencies between characteristics of a process or event according to the optimized criterion.

3. Mathematical modeling.

4. Choice and creation of the solution method. Such a set of quantity values (variables) which satisfies the set conditions-restrictions of a task is called the feasible solution. The solution found out from the multitude of feasible solutions, when the objective function achieves its maximal or minimal value, is called the task solution.

5. The task solving by computer. Tasks which describe the behavior of real objects, as a rule, have

a lot of variables and many dependencies between them. That is why computer-based algorithms help to save time when solving the problem.

6. The analysis of the obtained decision. Decision analysis can be formal and substantial. Mathematical analysis implies verification of the correspondence between mathematical model and real object (if the initial data are inserted correctly, if the computer programs operate well, etc.). In the end of the substantial analysis some changes can be made to the model and the whole process will be repeated.

7. The analysis of the decision stability. In order to verify the decision stability it is needed to change initial data within the limits of possible deflections, and then the decision behavior is checked by analytical or computational methods. This stage is supported by mathematical programming [2].

Tasks with several objective functions or with one objective function which takes vector values or values of more complicated nature are called multicriteria tasks. They are solved on the basis of game theory where it is supposed that a person who makes a decision gambles while trying to achieve the best result. Game theory — is the section of mathematics oriented to construction of formal models under the conditions of the competitive interaction between persons, ideas, alternatives strictly regulated by a table of wins and losses [5].

The meaning of game theory models is follow.

The vast majority of socioeconomic decisions have to be taken in view of contradictory interests having to do or with different individuals or organizations or with different aspects of the phenomenon under consideration. Traditional optimization methods cannot be applied in such cases. Normal extremum problems are about the choice of a decision by one individual, and the result of the decision depends on this choice, i.e. is determined by the actions of only individual. Such a scheme does not take into account the situations where decisions being optimal for one party are not optimal for the other one and the result of the decision depends on all the conflicting parties.

The conflict nature of such problems does not imply any enmity among those involved in, but rather indicates different interests. So we need a game theory to take into account all the mentioned problems.

Game theory is a part of broad theory studying the processes of making optimal decisions. It provides a formal language to describe the processes of making conscious, purposeful decisions involving one or several individuals in a context of uncertainty and conflict caused by a collision of the interests of the conflicting parties.

Game theory is a branch of mathematics that studies the formal models of making optimal decisions in a context of conflict. In this case, a conflict should be understood as a phenomenon involving various parties having different interests and opportunities to choose the actions available to them in accordance with these interests. Basically, game theory makes it possible to describe mathematically military and legal conflicts, sports events, "party" games and phenomena dealing with biological struggle for existence.

In terms of conflict, the opponent's striving to conceal their impending actions results in uncertainty. Conversely, uncertainty when decision-making (e.g. based on insufficient data) may be interpreted as a conflict of the decision-making subject with nature (the so-called games with nature). Thus, game theory is also viewed as a theory of making optimal decisions in terms of uncertainty. It allows mathematicians to work with some important aspects of decision-making in technology, agriculture, medicine and sociology. In some situations, game theory allows choosing the optimal type of behavior in uncontrollable onset of environmental conditions. Such a strategy of decision selection may be conventionally defined as "defensive".

The aim of game theory is to develop the rational pattern of a behavior of participants under conflict conditions, i.e. to determine the optimal strategy for each one of them.

In game theory applied in medical field, on the one hand, nature «chooses» a disease for a patient. And on the other hand, patient «plays» with nature struggling against disease. So here we have two players: nature and a decision making person (DMP). The DMP's task is to choose the optimal therapeutic approach.

The application of game theory in clinical practice supposes a conflict between a patient and a doctor — not fulfilled hopes for the recovery, dissatisfaction of the subjective expectation of a polite and courteous attitude, too high demands of a patient towards medical staff, etc. Conflicts in the clinical management are evident — between officials and practical doctors, insurance companies and hospitals, etc. Conflict of sides is the most important element of the game and normal event of the social life. A conflict can take place at the inner personal level, level of interpersonal interaction, between social groups, states.

The conflict formation is often explained by objective conditions: any development predetermines the conflict formation which can't be avoided. Studying the problems of the conflict development, it is necessary to be concentrated on the ways to solve them, their transformation to not dangerous condition which can be controlled and changed by a person himself. This way the necessity of the conflict solution appears, including the usage of the decision-making theory by the mathematical game theory.

If during the decision-making process we do not receive or lose information, the decision-making process can be considered as a momentary act. And task becomes static. On the contrary, if we receive or lose information when solving problem, then such a task is called a dynamic one. In dynamic tasks it is expedient to make decisions step by step (multistep decision). Task like this are solved by dynamic programming mathematical methods.

In professional activity doctor constantly faces the situations where information turns out incomplete and only indirectly connected with what doctor needs to know about a patient in reality. In these cases a doctor has to make decisions about a diagnosis and treatment under the conditions of indeterminacy (inaccuracy, illegibility, fuzziness, fairness, etc.). The additional quantity of information submitted to a doctor isn't always meant to decrease the indeterminacy.

Diagnosis and the choice of an action are terms used in decision-making theory applied in different areas of human's activity. In medicine they are equivalent to the terms of diagnostics and treatment. Decision-making in the diagnosis and treatment processes are tightly connected and should be considered together [1].

As it was mentioned above, the additional information isn't always sufficient to remove the indeterminacy which a doctor comes across with during the work with a concrete patient. That's why the selection of methods, which will help to the doctor to make a decision about a diagnosis according to the available data in the most efficient way and to choose the optimal decision, is very topical**.**

The term "optimal treatment" lies in the frames of the conception of maximally expected value and minimally expected losses which is also connected with it, and it is the important moment in the treatment choice.

For example, it is necessary to analyze the medical data from the point of view of the diagnostic value, i.e. to determine which signs and symptoms are the most important for diagnosing (maximally informative weight, minimally information loss).

A person isn't capable to extract all the data which can be in hidden form. It is connected with several reasons, in particular, for example, with the errors of observers, misinterpretation of results of diagnostic tests (for example, roentgenograms), insufficient accuracy of diagnostic tests.

For more clear understanding of the proposed material, we offer students the following situational fragment:

«Which of the tasks below should be solved by game theory?

- selection of a rational diet;
- problem of rational use of raw materials;
- selection of resource-saving technologies;
- mixture composition;
- determination of correlation between molecular-genetic origin of a disease and its phenotypical manifestation in form of symptoms;
- estimation of patient care institution effectiveness;
- analysis of actual data about diseases on phenotypical level by health history containing the information about diseases dependence and its development;
- disease identification and choice of treatment tactics;
- task of differential diagnostics;
- making a decision about surgical intervention;
- forecasting of the stroke consequence;
- management problem of hospital bed usage».

Game theory uses probability theory. The powerful tool of the probability theory is Bayes' theorem. By means of Bayes' formula it is possible to accumulate the information which comes from different sources with the aim of confirmation or non-confirmation of the certain hypothesis (diagnosis). Bayes' formula allows to use together the observed data and information known before by means of conditional probabilities for the solution of the differential diagnostics task.

As a situational task, we can offer the following.

«Based on common statistical information we know that 3 % of population are suffering from a certain disease A. The probability of this event is 0.03. Let us suppose that we need a test B (method B) to diagnose this disease in patients. And we also know that this test is correct in 90 % of cases. So the probability of this event when we correctly diagnose disease A by test B is equal to 0.9. This is situation when the individual is ill when he is actually ill. In addition we know that if patient is healthy and we try to apply test B in order to diagnose disease A, then the test B could show that patient has disease A when in fact he has no any disease. And let it happens in 20 % of cases. So the probability of a mistake when using test B is equal to 0.2. We ought to say that 0.9 is probability of a true-positive diagnosis and 0.2 is the probability of a false-positive diagnosis. Now the question — what is the probability to be right when diagnosing disease A in a patient by test B?».

Solution of the problem is follow.

Let us define: event H — patient has a disease A. Event «not H» – patient is healthy, event «T/H» — true-positive diagnosis (test B shows that patient has disease A and it is correct), event «T/not H» — false-positive diagnosis (test B shows that patient has disease A, but it is not right). So P(H) = 0.03. P(not H) = 1– P(H) = 0.97, P(T/H) = 0.9. And P(T/not H) = 0.2. Now we can find solution using Bayes' formula:

$$P(H/T) = \frac{P(T/H)P(H)}{P(T/H)P(H) + P(T/not\ H)P(not\ H)};$$

$$P(H/T) = \frac{0.9 \times 0.03}{0.9 \times 0.03 + 0.2 \times 0.97} = 0{,}122\ .$$

This result means that doctor can define disease A correctly only in 12.2 % of cases when using test B for that! Even if this method is correct for 90 % of sick patients! And this is the power of mathematical theory [4].

Bayes' theorem is applied for the decision-making process in expert systems. The work scheme of Bayes' expert system lies in the following.

Let a patient be suspected in having the flu. This way, there is some hypothesis *H*, which lies in the fact that a patient will have the flu, not something else. Let's think that in medical establishments on the basis of statistic data obtained earlier a priori (initial) probability *P(H)* is known that a patient will catch a flu in the given season and location. Let the sign *D* mean that a concrete patient has the high temperature.

It means, that initially we have a priori probability *P(H)* (in the example — a patient has got the flu), which is contained in the knowledge base. But having the evidence *D* (high temperature) and recalculated probability according to Bayes' formula, we can write it in the place of *P(H).* The receipt of one more evidence leads to the renewal (increase or decrease) of this probability. Each time the current value of this probability will be considered to be a priori for the application of Bayes' formula. In the result, collecting all the information regarding all the hypotheses (for example, diagnoses of diseases), an expert system comes to the final decision, marking the probable hypothesis as the expertise result.

With regard to the diagnostics problem, the Bayes' formula also allows choosing one of a number of diagnostic hypotheses based on the calculation of the probabilities of diseases by the probabilities of the symptoms displayed by patients. In this case, the concepts of *initial* and *eventual chances*, as well as of the *likelihood ratio*, are introduced.

Suppose there are two diseases: *H1*, posterodiaphragmatic myocardial infarction, and *H2*, ulcer disease. The existence of symptom *D* — pain in the epigastric region — is possible for each of the diseases.

The average probability of myocardial infarction for the adult population is P(H1) = 0.03, the probability of ulcer disease being P(H2) = 0.05.

The probabilities of symptom D — pain in the epigastric region — in each of the diseases are P(D|H1) = 0.40 (myocardial infarction) and P(D|H2) = 0.75 (ulcer disease). A patient with intense pain in the epigastric region is admitted to the emergency department. Which of the conditions is more probable?

(Footnote: given data are relative and can not be used as a reference information).

Ratio $\frac{P(H_1)}{P(H_2)}$ is *initial chances* (Ch_0) (i.e. chances that are not distorted by additional conditions).

Ratio $LR = \frac{P(D/H_1)}{P(D/H_2)}$ is a *likelihood ratio* and, in fact, is a correction factor (modification coefficient).

Eventual chances (final chances readjusted by additional conditions) — Ch_1 – it can be calculated as multiplication of *initial chances* and *likelihood ratio*:

$$\mathrm{Ch}_1 = \frac{P(D/H_1)}{P(D/H_2)} \cdot \frac{P(H_1)}{P(H_2)} = LR \cdot Ch_0$$

In terms of current task *eventual chances* Ch_1, in fact, are the answer on the previous question: «Which of the conditions is more probable?». By its help it is possible to estimate how much diagnosis «ulcer disease» is more probable, than diagnosis «posterodiaphragmatic myocardial infarction» with a glance to prevalence of diseases in population and in patient when having symptom «pain in the epigastric region».

Comment: Designated variables are yielded by double application of the Bayes' formula for one complex of symptoms typical for two different diseases and by getting of left and right rations of the formula:

$$\frac{P(H_1/D)}{P(H_2/D)} = \frac{P(D/H_1)}{P(D/H_2)} \cdot \frac{P(H_1)}{P(H_2)_1}$$

The situational task is:

«For the task given above figure out:

a) initial chances (0,6);

b) likelihood ratio (0,53);

c) eventual chances (0,32);

d) which of the diagnoses is more probable (ulcer disease)?».

Not less relevant is the technology of the verification of a diagnostic test reliability and the notions of sensitivity and specificity. Let's consider them.

The result of some test and two hypotheses regarding the function of distribution of this test result are given. It is necessary to make the best choice between these two hypotheses.

Regarding a medical diagnostic test, this statement can be paraphrased in the following way. The random population of patients, who can be in one of two states regarding some disease — norm or pathology — is given. The function of distribution of some test result corresponds to one of these states. It is required to make the best choice between these two states for each patient, i.e. practically to diagnose "norm" or "pathology" on the basis of a diagnostic test. The term "norm" is used here as "not pathologic state" [6].

The reliability of a test used to distinguish healthy people from sick people can be characterized by means of such test characteristics as sensitivity and specificity.

In an ideal world, medical tests must always be correct: a positive result of a test must indicate that there is a disease, while a negative one must indicate that there is no disease. In reality, however, any test has its drawbacks. To assess the "quality" of any test proposed for the first time, its results have to be compared with the actual state of things. Four scenarios are possible for that (table 1).

The disease we are interested in is present in cell "a" of the table, the results of the test being positive; due to this fact, such a result is called true-positive. In cell "d", there is no disease, and the result of the test is negative, such a situation being called a true-negative result. The results of the test in both these cells coincide with the patient's actual condition and whether they have or do not have the disease.

Cell "b" stands for the individuals not having the disease, whose test result is, however, positive. As these test results falsely imply there is a disease. They are called false-positive results. The individuals in cell "c" do have the disease, but negative test results have been obtained for them. These results are designated as false-negative, as they falsely imply that there is no disease.

Any diagnostic test may be assessed in such a way. The quantitative characteristic of a test quality with regard to the true diagnosis is its sensitivity and specificity.

Sensitivity — is the test ability to give positive answer when examined patient in fact sick or true-positive in relation to considered disease (that is to say to acknowledge an individual as sick when he is really sick according to the test results):

$$\text{Sensitivity,\%} = \frac{a}{a+c} \times 100\%$$

Specificity — is the test ability to give negative answer when patient does not suffering from disease or is true-negative with respect to considered disease (that is to say to acknowledge an individual as healthy when he is really healthy):

$$\text{Specificity,\%} = \frac{d}{d+b} \times 100\%$$

The first step in the assessment of a test is determining the patient's "true" status.

Let us consider an example. It is known that the gold standard (true diagnosis) for breast cancer diagnostics is the histopathology confirmation of cancer in the samples obtained during surgical intervention.

Table 1

Test results

Test\State	Disease was diagnosed	Disease was not diagnosed
Positive test	a (true-positive)	b (false-positive)
Negative test	c (false-nagative)	d (true-negative)

Table 2

Results of comparing two methods

Test\State	Cancer	No cancer
FNB positive	14	8
FNB negative	1	91

A test with fine-needle aspiration biopsy (FNA) is proposed as an alternative. To assess the quality of the FNA test, its results were compared with the results obtained from a histopathology study of the same group of women (table 2).

The situational task is following:

«Figure out the sensitivity (*Sensitivity* = 14/15 = 0.93 or 93%) and specificity (*Specificity* = 91/99 = 0.92 or 92%) values for data adduced in table 2.

Tasks from the area of "decision-making" appear when a task is so complicated that for its setting and solution the appropriate formalization apparatus can't be determined at once and when the task setting process requires the participation of specialists in different knowledge domains. For these situations the technology of the "decision-making" has special approaches, techniques and methods. For the beginning the area of the decision-making problem (problem situation) is defined, factors which influence its solution are revealed, methods and techniques, which allow to formulate a task so that a decision would be made, are selected. Then an expression, which connects the aim with the ways of its achievement, is obtained. All this is realized in mathematical models — different criteria (functioning criterion, criterion or index of efficiency, objective function, etc.).

If one succeeds in obtaining the expression which connects aims with means, then a task can be solved practically always. It is easy to obtain such expressions if a law which connects an aim with means is known. If a law isn't known then it is necessary to choose the other way to reflect problem situations. The patterns on the basis of statistical researches or functional dependencies can be defined. If even this can't be done, then a theory which contains the set of statements and rules which allow to formulate the conception and construct on its basis the decision-making process, is chosen or developed. If the theory doesn't exist, then a hypothesis is set up and imitation models are created on its basis, by means of which the possible variants of a research are investigated.

In order to help to set a task on the tight schedule, analyze aims, provide with possible means, to choose the required information (characterizing the condition of the decision-making and influencing the choice of criteria and restrictions) and ideally to obtain the expression which connects the aim with the means, system representations, techniques and methods of system analysis are applied.

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ТЕОРЕТИЧНІ АСПЕКТИ ПРОЦЕСУ ПРИЙНЯТТЯ РІШЕННЯ В МЕДИЦИНІ З ПРИКЛАДАМИ СИТУАТИВНИХ ЗАДАЧ

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З урахуванням власних професійних особливостей кожен фахівець в тій чи іншій мірі стикається з труднощами прийняття рішення. Однак є кілька галузей людської діяльності, де можна застосовувати процес прийняття рішень як звичайну і базову професійну навичку. Медична діяльність, що є послідовним процесом діагностики та лікування, є типовим прикладом такої галузі. Методи прийняття рішень універсальні, хоча їх успішне застосування великою мірою залежить від професійної кваліфікації фахівця, який повинен точно розуміти особливості системи, яку він вивчає, і повинен знати, як поставити задачу. Кафедра медичної та біологічної фізики і медичної інформатики Харківського національного медичного університету за підтримки кафедри біомедичної інженерії Харківського національного університету радіоелектроніки розробила і впровадила лекцію та практичне заняття «Прийняття рішень в медицині», тематика яких актуальна тим, що лікар зустрічає проблему вибору методу рішення в різних медичних завданнях (збір даних пацієнта, діагностика та тактика лікування). Мета впровадження цієї теми — з'ясувати можливість опанування студентами різних спеціальностей питань щодо практичного застосування елементів теорії прийняття рішень у професійній практиці. Під час проведення практичного заняття студенти отримують початкові дані, проводять аналіз, виявляють фактори ризику та чинники захворювання. На основі цієї інформації студенти формують множину альтернатив, після чого обирають відповідний метод пошуку оптимального рішення та застосовують метод до діагностичного або лікувального процесу.

Ця методика відпрацьована на заняттях із застосуванням ситуативних завдань. У заняттях взяли участь не тільки українські, але й іноземні студенти, які позитивно оцінили їх проведення. Методика викликала дуже жвавий інтерес із подальшим продовженням дискусії.

Ключові слова: *процес прийняття рішень, освіта, медична інформатика, теорема Баєса.*

ТЕОРЕТИЧЕСКИЕ АСПЕКТЫ ПРОЦЕССА ПРИНЯТИЯ РЕШЕНИЯ В МЕДИЦИНЕ С ПРИМЕРАМИ СИТУАЦИОННЫХ ЗАДАЧ

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С учетом собственных профессиональных особенностей каждый специалист в той или иной степени сталкивается с трудностями принятия решения. Однако есть несколько областей человеческой деятельности, где можно применять процесс принятия решений как обычный и базовый профессиональный навык. Медицинская деятельность, являющаяся последовательным процессом диагностики и лечения — типичный пример такой области. Методы принятия решений универсальные, хотя их успешное применение в значительной степени зависит от профессиональной квалификации специалиста, который должен точно понимать особенности системы, которую он изучает, и должен знать, как поставить задачу. Кафедра медицинской и биологической физики и медицинской информатики Харьковского национального медицинского университета при поддержке кафедры биомедицинской инженерии Харьковского национального университета радиоэлектроники разработала и внедрила лекцию и практическое занятие «Принятие решений в медицине», тематика которых актуальна тем, что врач встречает проблему выбора метода решения в различных медицинских задачах (сбор данных пациента, диагностика и тактика лечения). Цель внедрения этой темы — выяснить возможность овладения студентами разных специальностей вопросов практического применения элементов теории принятия решений в профессиональной практике. Во время проведения практического занятия студенты получают исходные данные, проводят анализ, выявляют факторы риска и факторы заболевания. На основе этой информации студенты формируют множество альтернатив, после чего выбирают подходящий метод поиска оптимального решения и применяют метод к диагностическому или лечебному процессу.

Эта методика отработана на занятиях с применением ситуативных задач. В занятиях приняли участие не только украинские, но и иностранные студенты, которые положительно оценили их проведение. Методика вызвала очень большой интерес с последующим продолжением дискуссии.

Ключевые слова: *процесс принятия решений, образование, медицинская информатика, теорема Байеса.*