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ORIGINAL ARTICLE

OPTIMIZATION OF TESTS FOR VERIFICATION OF A DIAGNOSIS MADE BY A GENERAL PRACTITIONER (GP)

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Introduction: In a GP's work, the fundamental problem is the accuracy of the diagnosis under time constraints, cost limitations on health care and medical standards. A GP selects the medical tests for verification of a hypothetical (preliminary) diagnosis made after an interview and physical examination. Optimization of such verification tests as urine, blood, ultrasound examination and simple X-ray examination in order to improve the diagnosis accuracy has been attempted in the paper. Diagnostic potential, cost and precision of tests have been accepted as optimization criteria.

Methods: For a health problem, a set of preliminary diagnoses is given. The diagnostic potential of tests in verification of the diagnosis from this set is determined using the Analytic Hierarchy Process. Then for each of these diagnoses, a set of tests with sufficiently great total diagnostic potential and minimal cost is found using a binary linear programming problem. The precision of tests in verification of the diagnoses is estimated using medical expert intuition. Then the pairs (hypothetical diagnosis, test) with the greatest coefficient of test precision impact in verification of the hypothetical diagnosis are selected. Finally, the recommendations for improving precision of the selected tests are defined.

Results: In the case study, a lumbar pain health problem is considered. Six preliminary diagnoses and four tests have been theoretically considered, i.e., no sample of patients. Two recommendations for the tests have been formulated.

Tables: 5 • **References:** 23 • **Full-text PDF:** http://www.pjambp.com • • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

Discussion and Conclusions: A quantitative method for indicating week points of medical tests in order to improve diagnosis accuracy has been proposed. A limitation of the case study is the estimation of diagnostic potential of tests and their precision by one medical expert only.

Keywords: diagnostic potential of test, test cost, test precision, Functional Resonance Analysis Method, expert method, Analytic Hierarchy Process

INTRODUCTION

In GPs' work, the fundamental problem is the accuracy of the diagnosis under time constraints, the cost limitations imposed on health care, and medical standards. The GP should prepare a diagnosis and decide what to do: start the treatment by themselves or direct the patient to a specialist or direct the patient to a hospital. After an interview and physical examination, the GP makes a hypothetical diagnosis. They select the medical tests for verification of this preliminary diagnosis. The tests that the GP can refer for are: urine, blood, ultrasound examination and simple X-ray examination. The Functional Resonance Analysis Method (FRAM) [7,17] model of this process has been provided in paper [13]. FRAM is a system-oriented approach to safety. In the FRAM method, the emphasis is put on function (activity) performance variability that is the key feature of the socio-technical systems with a high human influence on the safety. FRAM is functionality oriented, i.e. emphasis is put on functions and interactions among them. In the FRAM [7,17] model, its functions are connected from their output aspects O into aspects: input I, control C, time T, precondition P, resource R of the other or the same function. FRAM is more oriented on the human factor than such a system-oriented approach to safety as the System-Theoretic Accident Model and Process (STAMP) [10]. Computer-aided diagnosis [9,23] is an important support in the diagnostics process. Under-testing may result in delayed or erroneous diagnosis, while over-testing can cause a cascade of unnecessary activities and costs [3,15]. Therefore, selection of tests for verification of primary diagnosis is an important issue. Medical diagnostics with medical test costs have been studied in the papers based on the following approaches: naive Bayes classification [2], decision trees [11], genetic algorithms and fuzzy logic [4], rough sets [5], Analytic Hierarchy Process [1].

An additional difficulty is the variability of tests implied by the cases when: a patient is not properly prepared for the examination, the technical equipment is not suitable for the test, the medical laboratory technician is not correctly prepared, interpretation of results of tests by the USG or RTG specialist is not adequate, the result of the test is delayed. The variability of test performance can be characterized, according to FRAM, by precision and timing. Time constrains are important not only at an Emergency Department. Even in the work of a GP there are cases when time constraints cannot be neglected, e.g. when there is suspicion of cancer, aneurysm, urolithiasis. In the paper, timing is not considered. The values of scale for precision are as follows: precise, acceptable, imprecise or wrong. These variabilities influence the accuracy of the diagnosis. The problem of optimization by improving the precision of such verification tests as: urine, blood, ultrasound examination and simple RTG examination in order to improve the diagnosis accuracy made by the GP has been discussed in the paper. Diagnostic potential, cost and precision of verification tests have been accepted as optimization criteria.

Therefore, the following problem is studied in the paper. A patient with a health problem is coming to the GP. The GP should prepare a diagnosis and decide what to do: start the treatment by themselves or direct the patient to a specialist or direct the patient to a hospital. After an interview and physical examination, the GP makes a hypothetical diagnosis. In order to verify this diagnosis, they can order the tests from the set: urine, blood, ultrasound, simple X-ray. For each diagnosis, a set of tests with a total diagnostic potential not smaller than an assumed threshold value, but with minimal cost, should be sought. Verification tests are biased because of their variability and can be: precise, acceptable, imprecise or wrong [16]. The tests with the greatest threat of making a wrong decision about patient path because of test variability should be selected in order to improve the test precision. Recommendations for the selected tests should be developed.

In the case study analyzed in the paper, the patient with lumbar pain visits the GP. In this case for each of the six assumed preliminary diagnoses, a binary linear programming problem has been solved in order to find the set of tests with sufficiently great diagnostic potential but with minimal cost. Then, based on the obtained solutions, ordered pairs (hypothetical diagnosis, test) with the greatest coefficients of test precision impact in verification of the hypothetical diagnosis have been determined in order to improve the diagnosis accuracy. Finally, recommendations for these pairs have been given.

This paper is an extension of the paper [12], where the variability of tests has not been considered.

The structure of the paper is as follows. First the methods used for solving the presented problem are outlined. Then the case study is presented. Finally, there are discussion and conclusions.

METHODS

The Analytic Hierarchy Process (AHP) [14,19] is used in the proposed solution method. AHP is a linear algebra-based method that is used in a multi-step multi-criteria decision process supported by expert opinions. In this paper, the diagnostic potential estimation process is one-step, and in AHP-based approach, the comparison between pairs of test diagnostic potentials in verification of diagnosis D_k is done by a domain (medical) expert. The scale of relative importance when test T_i is not weaker than test T_j is given below:

9 - T_i is extremely preferred (absolutely more important) in regard to T_j,

7 - T_i is very strongly preferred (definitely more important),

5 - T_i - is strongly preferred (clearly more important),

3 - T_i - is moderately preferred (slightly more important),

1 - T_i - is equivalent (equally important) with T_j.

When intermediate values between the above are required, then the values from the set {2,4,6,8} can be assumed. These values determine the entry a_{ij} of a matrix of pair-wise comparison of diagnostic potentials of tests T_i, T_j in diagnosis D_k verification. The following condition $a_{ji}=1/a_{ij}$ needs to be satisfied. Hence, if T_i is extremely preferred (absolutely more important) in regard to T_j, then T_j is absolutely less important than T_i, i.e. $a_{ji}=1/9$.

The proposed solution method is as follows.

1. A set of preliminary diagnoses for the health problem is given. For each diagnosis, for each test, diagnostic potential of the test in verification of the diagnosis is determined using the Analytic Hierarchy Process (AHP) [14,19] method based on medical expert knowledge.
2. Then for each diagnosis, the set of tests with total diagnostic potential which is not smaller than the threshold value but with minimal cost is found using binary linear programming, as it is given in [12].
3. For tests for verification of the diagnoses, their variabilities, more exactly their precision, are estimated using medical expert intuition which delivers probability distribution over the set of values: precise, acceptable, imprecise, or wrong.
4. The ordered pairs (hypothetical diagnosis, test) selected in point 2. with the greatest product of diagnostic potential of the test and test precision in verification of this diagnosis are calculated. These pairs are such that the focus should be put on improving precision of tests used in verification of primary diagnosis made by the GP.
5. Recommendations for improving the tests in verification of the diagnosis found in point 4. are defined.

In comparison with paper [12], points 3., 4., 5. are new.

As a result of point 1., the sum of test potentials for each diagnosis is equal to 1. Test potential expresses relative power of a test when comparing with the other test. The sum of test potentials equal to 1 does not indicate that it is sufficient to verify the diagnosis.

In order to present the binary linear programming problem (BLPP) [12] for diagnosis D_k the following notation will be introduced.

$DP(D_k,T_l)$ – diagnostic potential of test T_l, where $l\in\{1,2,3,4\}$ and 1 for urine, 2 for blood, 3 for ultrasound and 4 for simple X-ray examination, in verification of diagnosis D_k obtained in point 1. of the above procedure,

x_l – binary decision variable; $x_l=1$ if test T_l should be executed for diagnosis D_k, $x_l=0$ otherwise,

$P_{min}\in(0,1]$ - required minimal total diagnostic potential (sum of potentials) of selected tests that belongs to left-side opened and right-sight closed interval; the same value has been accepted for all diagnoses,

c_l – test T_l cost.

BLPP for selection of tests for verification of diagnosis D_k

Constraint:

$$\sum_{l=1}^{4} DP(D_k,T_l) * x_l \geq P_{min} \quad (1)$$

Criterion:

$$min \sum_{l=1}^{4} c_l * x_l \quad (2)$$

The constraint imposes that decision variables satisfy the threshold of total diagnostic potential of selected tests requirements, while the criterion requires the minimal total cost value of these tests.

Performance variability of function or activity in FRAM is characterized by timing and precision [6,16].

The precision is graded using e.g., the following values [6,16]:
- precise (1),
- acceptable (2),
- imprecise (3),
- wrong (in [16] only) (4).

In order to simplify the analysis, the timing will not be considered.

In order to enable quantitative consideration, numbers 1, 2, 3, 4 in parenthesis above are assigned according to the principle:

The greater the "distance" from the required value "precise," the greater the number is.

The precision of test T_l in verification of diagnosis D_k is defined according to the formula:

$$P(D_k, T_l)=p_1+2*p_2+3*p_3+4*p_4 \quad (3)$$

where p_j is an estimation of the probability of occurring of precision value $j \in \{1,2,3,4\}$ of test T_l in verification of diagnosis D_k.

The coefficient of test T_l precision impact in verification of hypothetical diagnosis D_k is defined as:

$$I(D_k, T_l)= DP(D_k, T_l)*x_l*P(D_k, T_l) \quad (4)$$

where x_l indicates whether test T_l has been selected when solving BLPP for diagnosis D_k.

The greatest values $I(D_k, T_l)$ indicate the ordered pairs of (D_k, T_l) that the focus should be put on when improving precision of tests used in verification of primary diagnosis made by the GP.

RESULTS

A case study will be used for applying the developed method for improving the precision of tests used in verification of primary diagnosis made by the GP. Six preliminary diagnoses and four tests will be theoretically considered, i.e., no sample of patients.

The case of a patient with lumbar pain will be examined. The same case has been studied in paper [12]. Let the sample set of diagnoses contain the following elements:
- spine disease (SD),
- urolithiasis (U),
- aortic dissecting aneurysm (ADA),
- oncological disease (OD),
- pancreatic disease (PD),
- acute pyelonephritis (AP).

The abbreviations in the parentheses will be used further in the paper. The set of tests that the GP can order contain the following elements with their symbols:
- urine (UR),
- blood (B),
- ultrasound examination (US),
- simple RTG examination (X).

The estimation of diagnostic potentials has been based on medical expert knowledge of the second author of this paper and done using AHP [14,19]. In order to find the diagnostic potentials of tests in verification of the diagnoses, firstly, pair-wise comparison of diagnostic potentials has been given. Then, according to AHP using linear algebra, for each diagnosis, the diagnostic potentials of tests have been calculated. For each diagnosis, the sum of test potentials is equal to 1. Test potential expresses relative diagnosability of a test when comparing with the other test. The sum of test potentials which is equal to 1 does not indicate that it is sufficient to verify diagnosis. The diagnostic potentials of tests UR, B, US, X in verification of the diagnoses SD, U, ADA, OD, PD, AP have been taken from paper [12].

Tab. 1. Diagnostic potentials of tests UR, B, US, X in verification of the diagnoses SD, U, ADA, OD, PD, AP from paper [12].

	Diagnostic potential for SD	Diagnostic potential for U	Diagnostic potential for ADA	Diagnostic potential for OD	Diagnostic potential for PD	Diagnostic potential for AP
P_{UR}	0.06575919	0.1153455	0.06567851	0.06756525	0.05981514	0.50636002
P_B	0.29657373	0.07727503	0.16215180	0.25128778	0.44370599	0.26326719
P_{US}	0.05746972	0.71126472	0.70649118	0.61358173	0.44370599	0.19524967
P_X	0.58019737	0.09611474	0.06567851	0.06756525	0.05277289	0.03512312

Tab. 2. For all diagnoses, the solutions of BLPP x_1-x_4 (selected tests), the values of the total diagnostic potential, and the total tests costs for the requirement: total diagnostic potential threshold equal to 0.9 taken from [12].

	x_1	x_2	x_3	x_4	Total diagnostic potential	Total tests cost
SD	1	1	0	1	0.94253	172
U	1	0	1	1	0.922725	165
ADA	1	1	1	0	0.934321	145
OD	1	1	1	0	0.932435	179
PD	1	1	1	0	0.947227	181
AP	1	1	1	0	0.964877	170

Tab. 3. Probability distribution of precision values of urine, blood, USG and simple RTG examinations in verification of hypothetical diagnoses proposed by the expert.

Precision values of examination	Probability distribution in [%]				
	Urine test	Blood test for diagnosis SD, U, AP	Blood test for diagnosis ADA, OD, PD	USG test	Simple RTG test
Precision	70	98	95	85	90
Acceptable	0	0	0	10	6
Imprecise	0	0	0	4	3
Wrong	30	2	5	1	1

Tab. 4. Precision of tests in verification of hypothetical diagnoses.

Precision of urine test	Precision of blood test in verification of diagnoses		Precision of USG test	Precision of simple RTG test
	SD, U, AP	ADA, OD, PD		
1,900	1,060	1,150	1,210	1,150

Tab. 5. Coefficients of tests: UR, B, US, X precision impact in verification of the diagnoses SD, U, ADA, OD, PD, AP.

D	Coefficient of test UR precision impact in verification of diagnosis D	Coefficient of test B precision impact in verification of diagnosis D	Coefficient of test US precision impact in verification of diagnosis D	Coefficient of test X precision impact in verification of diagnosis D
SD	0.1249	0.3144	0.0000	0.6672
U	0.2192	0.0000	0.8606	0.1105
ADA	0.1248	0.1865	0.8549	0.0000
OD	0.1284	0.2890	0.7424	0.0000
PD	0.1136	0.5103	0.5369	0.0000
AP	0.9621	0.2791	0.2363	0.0000

The UR, B, US, X-ray tests are complex tests. They consist of elementary tests, e.g., urine test for diagnosis U consists of a general urine test and urine culture. Costs of tests will be given in polish zloty (PLN). The prices of tests were taken from December 2020, as in paper [12]. Costs of elementary tests will be assumed according to service price list of University Clinical Hospital in Wrocław [20], provided there was such information in this list. Otherwise, the prices of the following elementary tests were taken from the sources: blood count with smear [8], phosphorus [18], total calcium [21], vitamin D concentration 25OHD3 [22].

For each diagnosis, the set of selected tests with minimal cost to meet the requirement that the total diagnostic potential should not be smaller than 0.9 have been calculated using binary linear programming; see Table 2. The total diagnostic potential threshold equal to 0.9 has been chosen as an example. For diagnosis SD tests UR, B, X have been selected, i.e., $x_l=1$. Sum of their diagnostic potentials is equal to 0,94253, while their cost is 172 PLN.

Now precision of tests will be presented. Probability distributions of precision of the considered four tests over the set of values: precise, acceptable, imprecise or wrong, proposed by the expert is given in Table 3. When in column heading there is no list of diagnoses, it means that the column is for all diagnoses. As an example, let us consider the precision of the urine test, where the value “precision” occurs with a probability of 70 %, while “wrong” with 30 %. The main causes of the last value are: non-prepared patient, incorrect intake, improper storage.

According to these estimated distributions, precision of tests in verification of hypothetical diagnoses have been calculated using expression (3) and given in Table 4.

In Table 5, there are coefficients of tests: UR, B, US, X precision impact (see expression (4)) in verification of the diagnoses SD, U, ADA, OD, PD, AP for tests that have been selected for the total diagnostic potential threshold 0,9. Diagnostic potentials have been taken from Table 1, selected tests – from Table 2, while precision of tests from Table 4. Value 0 indicates that the test has not been selected according to Table 2.

Pairs (hypothetical diagnosis, test) with the greatest coefficients of the test precision impact in verification of this diagnosis can be found. These values can be a support in searching for weak points of such tests as urine, blood, ultrasound examination and simple X-ray examination in order to improve tests impact in verification of hypothetical diagnosis. Then the recommendations in medical doctors' education and training processes will be presented. These recommendations can be used in modifying the medical standards. On the other hand, the results from Table 2 can be applied in selecting the most suitable tests in diagnostics process by the GPs.

In Table 5, the two greatest coefficients of test T_l precision impact in verification of hypothetical diagnosis D_k are for the ordered pairs: (AP, UR) and (U, US).

The results contained in Table 5 should be treated as suggestions, not as definite decisions. For example, the third greatest coefficients of test T_l precision impact in verification of hypothetical diagnosis D_k is for the pair (ADA, US), and it is near to the second greatest coefficient for (U,US). ADA is a serious health problem. Hence, the decision on wheter to improve or not improve the US standard for verification of ADA diagnosis should be carefully considered. This case will not be analyzed here because of the excessive number of medical details.

For the above two cases, the recommendations for training of medical doctors will be given now.

Recommendation concerning the *Urine* test in verification of diagnosis for *Acute pyelonephritis:* The doctor must provide the patient with the rules of preparation for the examination, e.g., content on the card.

Recommendations concerning the USG test in verification of diagnosis for *Urolithiasis*:

1. The doctor must provide the patient with the rules of preparation for the examination, e.g., content on the card.
2. Kidneys, ureters and the bladder must be dimensioned in mm or cm. An example of an imprecise description is: "Renal pelvis is moderately widened".

DISCUSSION AND CONCLUSIONS

A quantitative method for indicating weak points of medical tests in order to improve them for higher diagnosis accuracy has been proposed. In the method, for the primary medical diagnosis, the coefficients of the test precision impact in verification of this diagnosis are estimated. In the estimation, the following factors are analyzed: diagnostic potential, cost and precision of the tests in verification of the diagnosis. Having diagnostic potentials of tests obtained using AHP and test costs, a binary linear programming problem is solved in order to find the set of tests with sufficiently great total diagnostic potential but with minimal cost. Therefore, the method is different when comparing with typical usage of AHP, where diagnostic potentials of tests and test costs are subjectively weighted.

The method has been illustrated by the medical example of a patient with lumbar pain. In the case study, for two tests with the greatest coefficients of test precision impact in verification of hypothetical diagnosis, two recommendations for training of medical staff have been proposed. The research can be extended by taking into analysis more than two tests with the greatest coefficients of test precision impact in verification of the diagnosis.

A limitation of the case study is the estimation of diagnostic potential of tests and their precision by one medical expert only. In general, this estimation can be done by more than one expert. Now, it seems to be difficult to find statistical data to evaluate these parameters.

In order to simplify the analysis, timing has not been considered. When analyzing the timing, the following values: too early, on time, too late, not at all, can be used. The next research step may be the study with the variabilities of tests characterized by precision and timing.

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Study Design: Jan Magott, Irena Wikiera-Magott. **Data Collection:** Jan Magott, Irena Wikiera-Magott. **Manuscript Preparation:** Jan Magott, Irena Wikiera-Magott. The Authors declare that there is no conflict of interest.

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