Collaborative Deterministic and Stochastic Decision-Making Models in Health Care

Tetiana Shmelova[a], Abdel-Badeeh M. Salem[b], Volodymyr Smolanka[c], and Oleksandr Sechko[d]

[a] *National Aviation University, Liubomyra Huzara ave. 1, Kyiv, 03058, Ukraine*
[b] *Ain Shams University, Faculty of Computer and Information Sciences, Abbassia 11566, Cairo Egypt*
[c] *Uzhhorod National University, Narodna Square, 3, Uzhgorod, 88000, Ukraine*
[d] *Uzhhorod National University, Narodna Square, 3, Uzhgorod, 88000, Ukraine*

Abstract

The authors presented smart decision-making models for effective interaction of doctors and patients, doctors of various qualifications, and the choice of joint effective solutions in the health care system such as Non-Stochastic (Deterministic) and Stochastic (Decision Making in Risk and Uncertainty). There presenting intelligent Algorithms of the integration of Deterministic and Stochastic Decision-Making models and Finding the optimal solution in Uncertainty for building Collaborative Decision-Making Models for use in Healthcare **systems**. The Expert system for the estimation of the priority of patients for the Artificial Intelligence system developed.

Keywords 1

Artificial Intelligence, Expert Judgment method, Intelligent Decision Making in Risk, Decision Making in Uncertainty, Deterministic Model, Health Care, Collaborative Models, Medical Informatics.

1. Introduction

The interaction of doctors of various qualifications and the patient in the health care system is an urgent issue, both now and before. Patient-physician interaction is a potentially important factor in optimal communication during consultations as well as before treatment and during treatment, compliance, and follow-up care. Many authors share their experience of using integration models and solutions between doctors of different qualifications, between doctor and patient, between young and experienced doctors.

The model of interaction between doctors and patients in the health care system is understood as a product of analytical design, which is based on functional, behavioral, communicative, sociocultural aspects [1].

The collaborative decision making (CDM) has advantages in different organization systems, including in Aviation systems, where operator's decision making (DM) in difficult situations [2; 3; 4]. A properly managed solution can improve group results of decisions [4; 5].

The modern development of society involves taking into account the influence of sociocultural values on the patient's condition. For example in aviation, investigation of the evolution of the aviation system in the direction of sociotechnical system SHEL (1972) [8; 9; 10], show that the SCHELL model since 2004 complements the interface associated with the culture of human-operator and CRM (Crew resource management), "SCHELL model and CRM" - Software (procedures), Culture (culture), Hardware (machines), Environment, Liveware, Liveware (humans) [11; 12; 13; 17]. At the heart of the SHEL model is man as the most important component of the system. It is very important to take into account culture (C), the interaction between people (L-L), collaborative decisions (CDM), consistency

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EMAIL: shmelova@ukr.net (T.Shmelova); abmsalem@yahoo.com (Abdel-Badeeh M. Salem); vsmolanka@gmail.com (V.Smolanka), aleksander.sechko@gmail.com (O.Sechko)
ORCID: 0000-0002-9737-6906 (T.Shmelova); 0000-0001-5013-4339 (A-B.Salem); 0000-0001-7296-8297 (V.Smolanka); 0000-0002-4136-5511 (O.Sechko)

in the team of humans, the balance between cost and efficiency in rational solutions, the use of AI systems to solve and help a person in difficult situations. These additions to the conceptual model SHEL are considered in the evolution of the human factor models. Now the most relevant is the use of CDM models, especially in critical situations [3; 13].

The world's leading airlines have developed programs to prepare flight crew for air defense, which complement each other and integration. Aeronautical Decision Making (ADM) is a systematic approach that pilots must consistently use to select the best strategy according to the circumstances. Each decision can significantly increase or decrease the risk of successful completion of the flight and is based on the pilot's ability to make informed and timely decisions. Nowadays importantly CDM by all operational partners such as pilots of manned and unmanned aircraft, air traffic control services, airports, airlines, and ground operators on the basis of shared information on the flight process and ground handling of aircraft in an airport [3; 11; 12; 13].

International civil aviation organization (ICAO) constantly develops and improves, based on the evaluation of the risks and the proactive approach, which to oriented on operator. A modern approach, founded on the characteristics (performance-based approach – PBA), based on the next three principles monitoring [3; 12; 13]:

1. The main accent on desired/necessary results
2. DM, oriented on desired/necessary results
3. Using facts and data while DM

Herein the principle "using facts and data while DM" admits that tasks shall comply with the widely known in Western management criteria SMART [9]:

- Specific
- Measurable
- Achievable
- Relevant
- Timebound

The concept of ICAO assumes provision collaborative CDM between all operational partners [11; 12]. Implementation of the CDM requires the use of a modern information environment based on the concepts of System Wide Information Management (SWIM). Such a level of accuracy of task determination may be achieved only using the new methodology includes the process of Integration Stochastic and Non-Stochastic Uncertainty Models for Network Planning models in Conflict Situations [12; 13].

Nowadays, ICAO extended the existing and defined new approaches to improve the practical and sustainable implementation of preventive aviation security measures based on modern advances in information technology and Artificial Intelligence (AI). AI technologies have expanded considerably with successful applications in many areas and for support of humans in difficult situations, of cause.

The approaches in patient-physician interaction a patient-centered presented, improving interactions between young and experienced healthcare providers are confirmed by statistics data [6; 7].

The authors' proposal introduces in medicine the methodology of CDM for improving patient states that are used in aviation [5; 6] with the application of integrated models of DM and AI methods. The approaches in patient-physician interaction a patient-centered presented, improving interactions between young and experienced healthcare providers are confirmed by statistics data [6; 7].

The purpose of the publication:

- Analysis multi-DM in certainty using Network Planning Models for all participants of a process
- Working-out of smart models DM in Certainty, in Risk, and Uncertainty for the search of the optimal solution
- Integration of models DM in Certainty, in Risk, and Uncertainty
- To develop an Expert system (ES) as a knowledge-based system for estimation of priority of patients using Expert Judgment Method (EJM)

2. Collaborative Decision-Making Models

The CDM an uninterrupted process of presenting information and individual decision-maker by various interacting participants (in patient-physician and physician-physician interaction too), as well as providing synchronization of decisions taken by participants and the exchange of information between them. It is important to ensure the possibility of making a joint, integrated solution with partners at an acceptable level of efficiency. This is achieved by completeness and accuracy of available information. Solutions planning should provide using DM different models such as deterministic models; stochastic and non-stochastic of uncertainty models; the Markov and reflexion models. After analysis of the situation needs synthesis (aggregation) of stochastic models for the correction of the deterministic model. Algorithm of the integration of DM models for participants of a complex process (operators, patient-medic, medic-medic, etc.) was obtained.

2.1. Intelligent Algorithm of the integration of Deterministic and Uncertainty Decision Making models

Algorithm where indicated the analysis of the actions of operators with the aid of the Network Planning methods, DM in Risk and Uncertainty, EJM and obtaining of simple models with unambiguous decisions and ordered actions of patients and medics.

Intelligent Algorithm of the integration of Deterministic and Uncertainty DM models:

1. Deterministic models with ambiguous decisions and ordering actions of patients and medics. Deterministic models:

- Building a deterministic DM model with a lot of problems, and ambiguous decisions in specific stages using the Network Planning method - complex certainty DM model (Figure 1)
- Decomposition of main technology (problem/procedure/situation/conflict situation) on procedures
- Flowchart of performance technology procedures (procedure/situation/conflict situation) / ordering of procedures
- Determination of the times of operating procedures using the EJM (according to experimental, statistics, experience, skills data too)
- Structural-timing table of operational procedures and time on the procedures in main technology (procedure/situation/conflict situation)
- Network graph of main technology (problem/procedure/situation/conflict situation) and obtaining main critical time of performance all proceeding.

2. Optimization of schedule/plan of performance of main technology (problem/procedure/situation/conflict situation):

- Identification of difficult points where several alternative solutions and in next using the effective method of DM. In the presence of a large amount of statistical data and probabilities are used DM methods in Risk. In the absence of a large amount of statistical data and probabilities, are used DM methods in conditions of Uncertainty.
- Analysis each part of main technology using assessment by DM in Stochastic Uncertainty (DM in Risk) and Non-stochastic Uncertainty (DM in Uncertainty) methods.

3. Stochastic models for the determination of uncertainty moments, such as DM in Risk and DM in Uncertainty (Figure 1).
4. Deterministic models with unambiguous decisions and ordered actions of patients and medics - – integrated simplified certainty DM model (Figure 1).
5. Construction of a Decision Support System (DSS) for the attending physician, which are used:

- Model base (DM and CDM models)
- Database (specific treatment conditions)
- Knowledge base (expert assessments of specialized specialists)

6. DSS maintenance using statistical, expert and experimental data.
7. Building an AI system for intellectual assistance and support to the physician in difficult situations with Big Data.

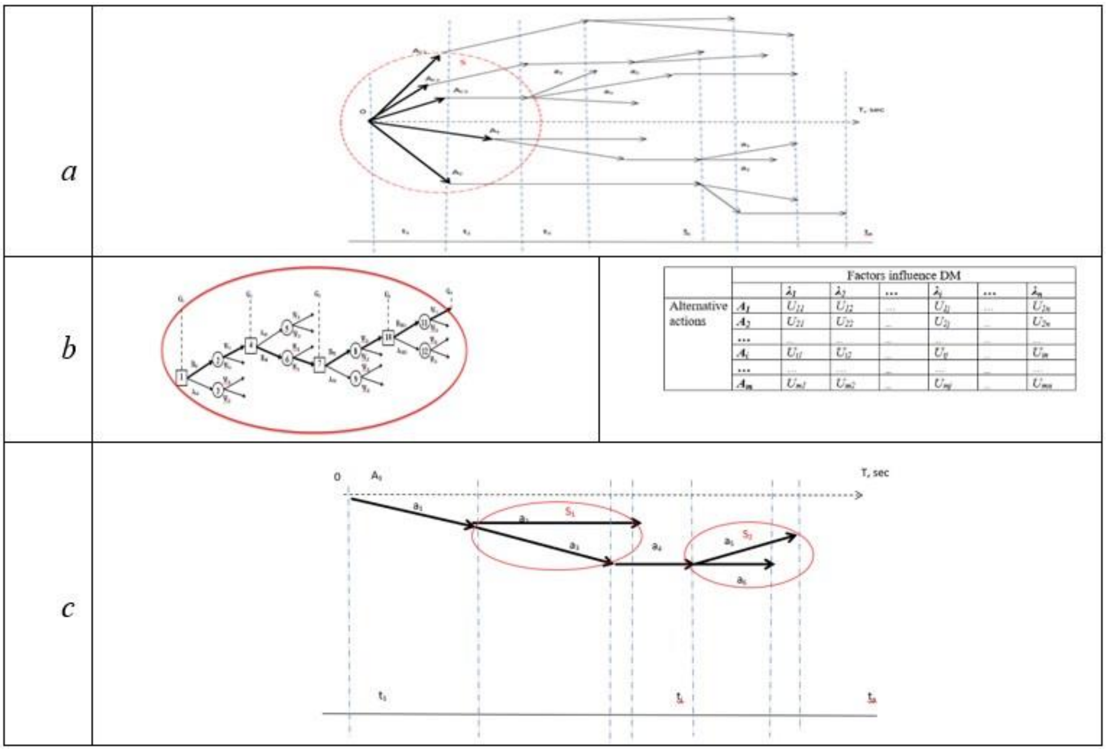

Figure 1: The integration certainty, risk and uncertainty DM models: a - complex certainty DM model; b - risk and uncertainty DM models; c – integrated simplified certainty DM model

In aviation, with the aim to optimize the solutions (pre-flight preparation, Air Traffic Control) the automated systems of preparation information and DSS were created [3; 13]. In the recent documents, ICAO defined new approaches - application of AI models the organization of CDM by all aviation operators using collaborative DM models (CDMM) based on general information on the flight process and features of the situation [11; 12; 14].

In the process of analysis and synthesis of DM models in situations makes sense to simplify complex models and solutions. So, for example, stochastic and non-stochastic of uncertainty, neural, the Markov, and GERT (Graphical Evaluation and Review Technique) - models, reflexion models, dynamic models may be integrated into deterministic models. The models for decision and predicting the situation using CDMM [14]. For the formation (modeling) of DM, operator has the property such as the ability to apply different levels of DM complexity depending on the factors that influence the DM [15].

The selection task of an optimal solution using the method of DM under uncertain-ty was obtained by means of the criteria of DM under uncertainty: Wald, Laplace, Savage, Hurwicz [13]. Each of the criteria has a set of differences in application. The main difference is the different levels of uncertainty of problem, types of situation (often, rare, first time), and complexity of care situation. For instance, the Laplace criterion is grounded on more optimistic assumptions (same situations what were); the Wald criterion is grounded on more pessimistic assumptions is used to find the optimal solution for the first time. The coefficient of optimism-pessimism is used in the Hurwicz criterion that can be used in different approaches from the most optimistic to the most pessimistic value. The Savage criterion is used in after situations for re-calculation decisions minimizes the losses.

2.2. Collaborative Deterministic and Stochastic Decision-Making Models

As known, the environmental conditions (natural, social, communication, financial) determine the reactions of humans, while the reaction of the latter, in its turn, changes the conditions themselves development of situation. For example, the systemic analysis has been carried out as well as the formalization of the factors which affect DM by operators in the Air Navigation System (individual-psychological, psycho-physiological and social-psychological) in the normal, difficulty, emergency situations [3; 8]. The impact of individual-psychological and socio-psychological factors on the professional activities of operators during the conflict situation and development from normal to catastrophic has been studied. On the basis of the reflexive theory of bipolar choice, the expected risks of DM have been studied and the influence of the external environment, previous experience and intention of the operator have been identified [3]. It is very important to create highly intelligent collaborative DM systems for people who are involved in solving one problem and influence the development of the situation.

In research are presented DM models for humans who taking part in solution important single problems in Health Care. There are such as medics, operators, physician, medics of different qualifications, and patients, of cause too. The authors have experience in building decision-making models in air navigation systems especially in emergency situations for operators (pilots of manned and unmanned aircraft, air traffic controllers, engineers, flight dispatch) [3; 4; 13; 14]. There are obtained the deterministic and stochastic models of DM for operators of the air navigation system with using of collaborative solutions of different operators. Were obtained the integrated models with using deterministic and stochastic DM models such as DM in certainty, risk and uncertainty, Markov chains; stochastic models type GERT's (Graphical Evaluation and Review Technique) network; neural network models; fuzzy logic models; reflexive models of bipolar choice; models of diagnostics of emotional state deformation in the activity of operators; graphical-analytical models of situation development; graphical-analytical models of decision-making for ANS operators [3; 13].

In Health Care, for example, the search for an optimal solution for effective medical care/treatment of patient A with alternative ways ($A_1; A_2; A_3$) of finding the patient in a simple situation *B*: in a hospital, day hospital, outpatient treatment, home treatment. Such options for finding patients with mild diseases are used now when the COVID-19 pandemic in the world, in many hospitals, need a reserve for patients with coronavirus disease [16].

Effective decision rules for patient care are determined using a deterministic model built using network planning methods. However, the deterministic model of DM, taking into account all the circumstances, turns out to be very complex (Figure 2), there are many suggestions from doctors, from patients with the construct wishes. The deterministic model of the DM in a situation where are many suggestions from participants (subjective factors) and external factors influence decisions (objective factors) are present in Figure 2. To simplify the deterministic model, it is proposed to resolve multi-alternative situations (*S*) using DM methods under conditions of risk and uncertainty.

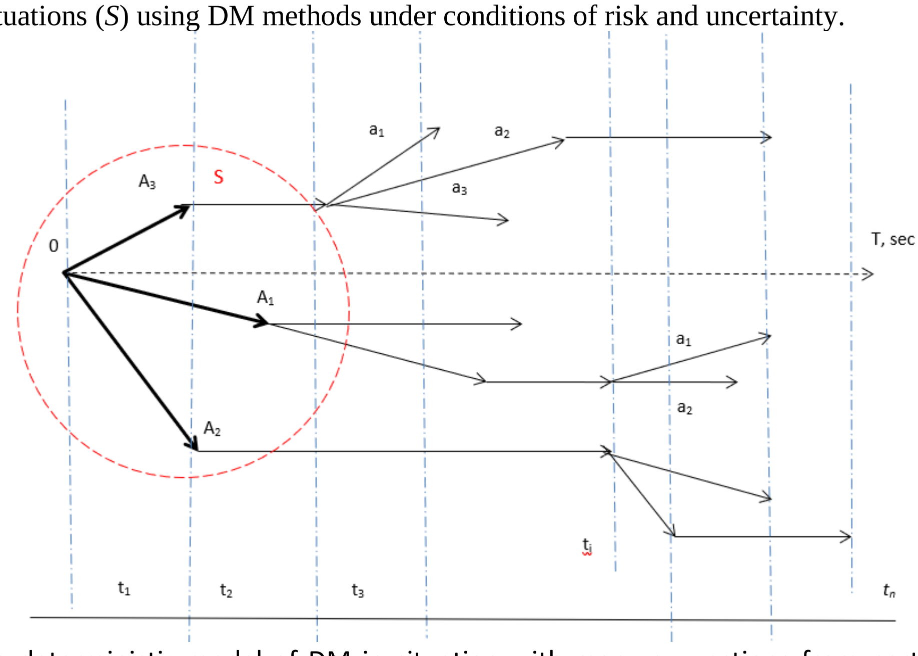

Figure 2: The deterministic model of DM in situation with many suggestions from participants of process

For example, the DM matrix with some alternative decisions and objective-subjective factors influencing DM is presented in Table 1. DM matrix consists of the next components:

1. Set of alternative actions:

$$\{A\}=\{A_1, A_2, \ldots A_i, \ldots, A_n\},$$

where

A_1 – finding the patient in hospital; A_2 – finding the patient in day hospital; A_3 – finding the patient in outpatient treatment

2. Set of factors:

$$\{\lambda\} = (F_1; F_2)$$

where

F_1 - objective factors: λ_1 - comfort of finding; λ_2 - service cost; λ_3 - remoteness; λ_4 - medical indications, etc.

F_2 - subjective factors: λ_5 – physicians' opinion; λ_6 - doctor opinion; λ_7 – patient-doctor opinion.

3. Set of outcomes $\{U\}$ – results / outcomes of expert's evaluations.

Table 1

The matrix of DM in Uncertainty

		F_1 - objective factors				F_2 - subjective factors		
A		comfort	cost	remoteness	indications	physician	doctor	patient
Alternative actions		λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
In hospital	A_1	5	6	10	10	8	5	2
In day hospital	A_2	6	7	7	7	7	6	7
In outpatient treatment	A_3	7	8	6	4	8	6	8
In home treatment	A_4	8	8	5	2	6	7	9

2.2.1. Intelligent Algorithm of finding of optimal solution in Uncertainty Decision-Making:

1. Formation of a multiplicity of alternative decisions $\{A\}$:

$\{A\} = \{A_1, A_2, \ldots A_i, \ldots, A_n\}$,

where

A_1 – finding the patient in hospital;

A_2 – finding the patient in day hospital;

A_3 – finding the patient in outpatient treatment;

A_4 – finding the patient in home treatment;

2. Formation of factors $\{\lambda\}$, that influence on selection of best solution:

$\{\lambda\} = \lambda_1, \lambda_2 \ldots, \lambda_j, \ldots, \lambda_m$,

where

F_1 - objective factors:

λ_1 - comfort of finding;

λ_2 - service cost;

λ_3 - remoteness;

λ_4 - medical indications;

F_2 - subjective factors:

λ_5 – physicians opinion;

λ_6 - doctor opinion;

λ_7 - patient-doctor opinion.

3. Formation of possible consequences $\{U\}$ that influence on selection:

$$\{U\} = U_{11}, U_{12}, \ldots, U_{ij}, \ldots, U_{nm},$$

where

U_{ij} - is defined according to the evaluation scale / regulatory data (F_1) and opinions of participant (F_2).

4. Estimation of factors that influence the selection of optimal solutions is realized with the help systems of the preferences of participants of the process. The opinions processed using AI methods if need. Coordination of opinions using EJM obtained [3; 12; 13; 17]. The graphical presentation Multi-Factor estimation and DM in a complex situation in Health Care in the Figure 3.

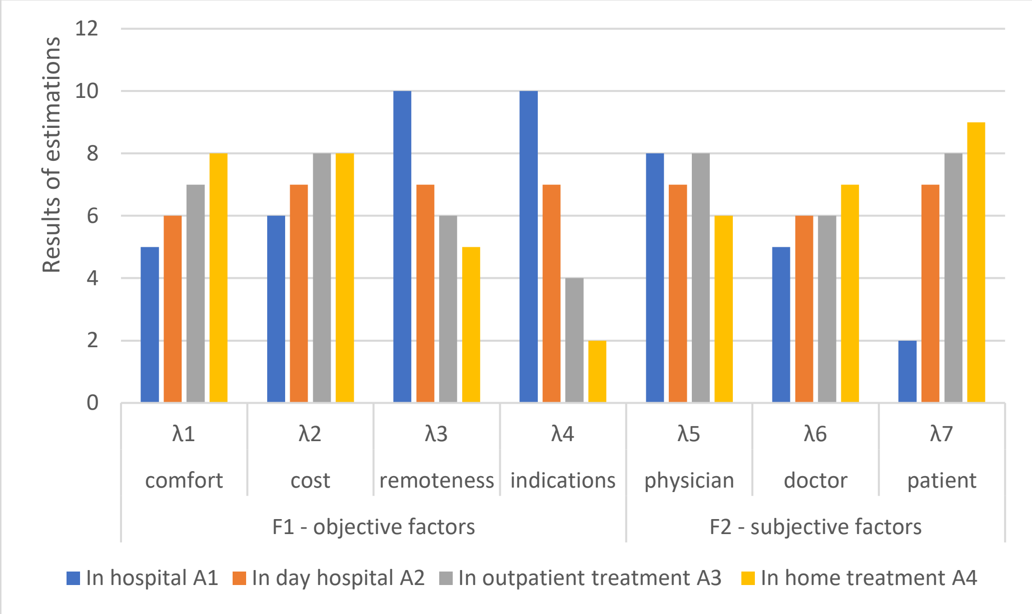

Figure 3: Graphical presentation Multi-Factor estimation and DM in complex situation in Health Care

5. Formation of decision matrix (Table 1) $M=\| M_i \|$.
6. Obtaining the optimal solution in the case of complex situations using methods of DM under uncertainty: Wald, Laplace, Savage, Hurwicz. Wald's (maximin)criterion is used if a rare case:

$$A^* = \max_{A_i}\left\{\min_{\lambda_j} u_{ij}(A_i, \lambda_j)\right\}.$$

Laplace's criterion is a case that is often encountered:

$$A^* = \max_{A_i}\left\{\frac{1}{m}\sum_{j=1}^{n} u_{ij}(A_i, \lambda_j)\right\}.$$

The optimal solutions using Wald, Laplace methods of DM presented in the Table 2.

Table 2
The matrix of DM with optimal solutions of DM in Uncertainty using Wald, Laplace methods

		F_1 - objective factors				F_2 - subjective factors			Solutions	
A		comfort	cost	remoteness	indications	physician	doctor	patient	Wald	Laplace
Alternative actions		λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	***maximin***	***max***
In hospital	A_1	5	6	10	10	8	5	2	2	6,57
In day hospital	A_2	6	7	7	7	7	6	7	**6**	**6,71**
In outpatient treatment	A_3	7	8	6	4	8	6	8	4	**6,71**
In home treatment	A_4	8	8	5	2	6	7	9	2	6,43

The Hurwitz criterion is used for decisions with varying degrees of optimism using the optimism-pessimism coefficient α:

$$A^* = \max_{A_i}\left\{\alpha \max_{\lambda_j} u_{ij}(A_i, \lambda_j) + (1-\alpha)\min_{\lambda_j} u_{ij}(A_i, \lambda_j)\right\},$$

where

α – is an optimism index ($0 \leq \alpha \leq 1$), α =0.5.

The optimal solutions using Hurwitz method of DM with different level of optimism - pessimism presented in the Table 3.

Table 3

The matrix of DM with optimal solutions of DM in Uncertainty using Hurwitz methods

		F_1 - objective factors				F_2 - subjective factors			Solutions	
A		comfort	cost	remoteness	indications	physician	doctor	patient	Hurwitz	
Alternative actions		λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	**α =0,5**	**α =1**
In hospital	A_1	5	6	10	10	8	5	2	6	**10**
In day hospital	A_2	6	7	7	7	7	6	7	**6,5**	7
In outpatient treatment	A_3	7	8	6	4	8	6	8	6	8
In home treatment	A_4	8	8	5	2	6	7	9	5,5	9

The Savage criterion (minimax regret criterion) is used to recalculate whether the decision was made correctly using the additional loss matrix r_{ij}:

$$A^* = \min_{\lambda_j} \max_{A_i} r_{ij}(A_i, \lambda_j),$$

where loss matrix:

$$r_{ij}(A_i, \lambda_j) = \Delta_{A_i} = \max_{\lambda_k} u_{ij}(A_i, \lambda_j) - u_{ij}(A_i, \lambda_j).$$

The following solutions were obtained: if a rare disease (Wald criterion) is the best solution - $A_2 = \max A_j = 6$ (A_2 – finding the patient in day hospital), with mild disease, often occurring (Laplace criterion), the optimal solution is - $A_2 = \max A_j = 6{,}71$ and $A_3 = \max A_j = 6{,}71$ (A_2 - finding the patient in day hospital and A_3 – finding the patient in outpatient treatment). Taking into account different degrees of optimism (Hurwitz criterion), for $\alpha = 0{,}5$, rationalism, optimal solution $A_2 = \max A_j = 6$ (A_2 – finding the patient in day hospital) and for $\alpha = 1$, optimistic assurance for recovery, optimal solution $A_1 = \max A_j = 10$ (A_1 – finding the patient in hospital).

There is a different approach to finding a solution. For rational CDM, each person involved in DM has analyzed are considering the current situation and then they together make joint decisions. For example, each participant of the process solved the first matrix of decisions, where alternative solutions are the condition of treatment such as in the hospital, in day hospital, in outpatient treatment, in-home treatment ($\{A\}$). The factors, influence the effectiveness of the condition of treatment for patients: comfort, service cost, remoteness, medical indications (F_1 - objective factors $\{\lambda\}$). The output data of individual solutions from the first matrixes are included in the initial data for the second matrix. In second CDM matrix determines the optimal solution by all participants of the process of cure (F_2 - subjective factors $\{\lambda\}$ – the opinions of the participants about the process of treatment).

3. What is next

In the future authors are planning to predict real-cared results using an artificial intelligence system. The machine learning algorithm based on supervised learning and performs a regression technique that finds out a linear relationship between *x* (input) and *y* (output). The input variable *x* data features of care and treatment, the output variable *y* predicts real-cared results of cure [13; 15; 18; 19] (Figure 4).

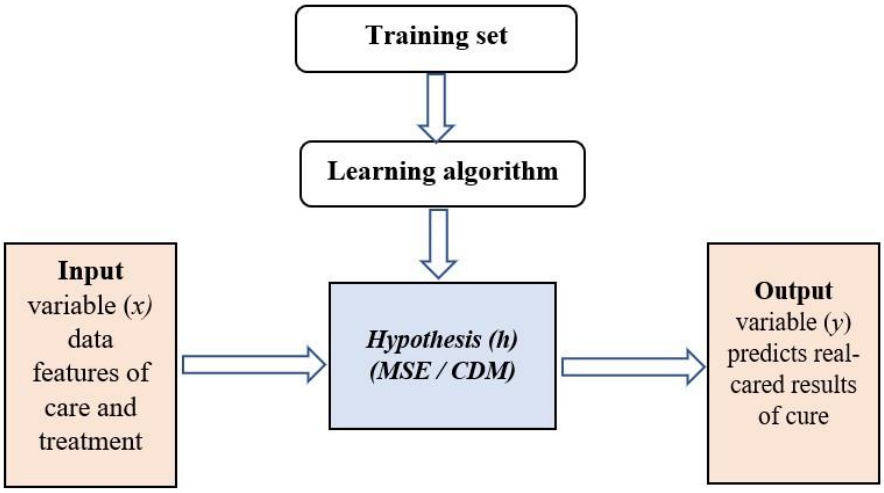

Figure 4: The intellectual connection between input variable x (data features of care and treatment), the output variable y (prediction real-cared results of cure)

The function of the minimization of the difference between the predicted values and ground truth measures the error difference. This function is also known as the Mean Squared Error (MSE) function [13; 15]. Using the MSE function may change the values coefficients of regression such that the MSE value settles at the minima. For updating the coefficients method of gradient descent used. The learning rate is very important because a smaller learning rate could get closer to the minima of error but takes more time to reach the minima. A larger learning rate converges sooner but there is a chance that MSE function could overshoot the minima. To create a new AI system, need Big data and CDM of participants of the modeling process.

4. Conclusion

The CDM an uninterrupted process of presenting information and individual DM by various interacting participants, as well as providing synchronization of decisions taken by participants and the exchange of information between them. It is important to ensure the possibility of making a joint, integrated solution with partners at an acceptable level of efficiency. This is achieved by completeness and accuracy of available information. Solutions planning should provide using DM different models such as deterministic models; stochastic and non-stochastic models. After analysis of the situation needs synthesis of stochastic models for the correction of deterministic model.

The authors' proposal introduces in medicine the methodology of CDM for improving patient states that are used in aviation with the application of smart integrated models of DM and AI methods and techniques. An intelligent algorithm of the integration of DM models for participants of a complex process (operators, patient-medic, medic-medic, etc.) was obtained. Algorithm of the actions of participants in complex situations for obtaining simple models with unambiguous decisions and ordered actions of patients and medics presented.

The example of the service situation of patients in Healthcare, the search for an optimal solution for effective medical care/treatment of patients presented.

The obtained DM models can be applied in the DSS of physicians to serve patients in future medical AI-based systems.

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