Hybrid Expert System for Collaborative Decision-Making in Transportation Services of Healthcare Needs

Tetiana Shmelova[a], Oleksandr Sechko[b]

[a] *National Aviation University, Liubomyra Huzara ave. 1, Kyiv, 03058, Ukraine*
[b] *Uzhhorod National University, Narodna Square, 3, Uzhgorod, 88000, Ukraine*

Abstract
The authors presented a Hybrid Expert System for Collaborative Decision-Making (CDM) in transportation services of healthcare needs. The analysis of the process of delivering medical supplies to remote areas, in a smart city using UAV, groups of UAVs as a decision-making process of several participants presented. Analysis multi-DM using network planning models for all participants of a process and integration of models DM under Risk, and Uncertainty showed. Optimization with minimal cost and maximum safety example delivering medical supplies for the smart city using UAVs presented. This is achieved by fullness, precision, and real-analysis of existing data. Planning of solutions provides using deterministic, stochastic, and non-stochastic decision-making models; methods of dynamic programming and reflexion models.

Keywords 1
Artificial Intelligence, Expert System, Decision-Making in Risk, Decision-Making in Uncertainty, Deterministic Model, Health Care, Collaborative Decision-Making Models, Transportation/Service/Logistic.

1. Introduction

There are many systems based on knowledge and experience such as expert systems (or decision support systems) for effective support of medicine, for example, post-disaster patient transportation, transporting important and urgent cargo. Main modes of transport (air, water, and land transport) are widely used in civil and military emergency medicine due to the fast speed of transfer, effectiveness in difficult situations, but air, water, and land transport have various opportunities for effective use [1–3].

Nowadays, unmanned aviation has been rapidly developing especially for the realization of intelligence solutions, for example in smart-city [3; 4]. New technology and data obtained by modern methods, such as using UAVs, to monitor cities in near real-time help to simulate minimal risk in situations proposed for future solutions according to theoretical principles of sustainable urbanism [4]. The development of Unmanned Aerial Systems (UAS) based on Unmanned Aerial Vehicles (UAVs) is currently being carried out by many industrially developed countries of the world. Until recently, UAVs had a military purpose, while the use of the UAS is effective both in civilian and military tasks, for example, in dealing with the effects of emergencies, natural disasters, agriculture, reconnaissance, aerial photography, and for the healthcare industry [3; 5; 6]. More common UAV applications in healthcare have started from the provision of disaster estimation where other means of access are strictly limited [2; 3; 7]; delivering aid medicines packages, medicines, vaccines, blood, and other medical supplies to remote areas, for example, mountain area [6]; ensuring the safe transport of samples and disease test kits to highly contaminated areas; potential for quick access to automated defibrillators for patients in cardiac arrest [1]. Recently work on UAVs for direct transportation and medical evacuation has started of difficult ill patients [3; 4; 6].

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EMAIL: shmelova@ukr.net (T.Shmelova); aleksander.sechko@gmail.com (O.Sechko)
ORCID: 0000-0002-9737-6906 (T.Shmelova); 0000-0002-4136-5511 (O.Sechko)

International civil aviation organization (ICAO) supports new applications of aviation and implement new conceptual models for the search for optimal solutions [8-10]. Interaction can be done in the form of collaborative decision-making (CDM) by all participants based on the reciprocal exchange of helpful data [10]. The authors propose to introduce in medicine the methodology of CDM for improving the effectiveness of transportation that is used in aviation [11; 12] with the application of integrated models of decision-making (DM) in certainty, risk, and uncertainty, and Artificial Intelligence (AI) methods.

The purpose of the publication:

- *The analysis of the process of delivering medical supplies to remote areas, in a smart city, and between cities using UAVs and groups of UAVs as the multi-DM process of several participants.*
- *Analysis of the multi-DM using network planning models for all participants of a process and integration of DM models in risk and uncertainty.*
- *Optimization delivering medical supplies to remote areas, in a smart city, and between cities using UAVs and groups of UAVs.*

2. Collaborative Decision-Making Models for Transportation

2.1. Main scientific results

The CDM is an effective process of exchanging data, individual and collaborative decision-maker by different contacting members. Determination of potential participants of the process of delivering medical supplies depends on the purpose of the task, characteristics of medical supplies, the urgency of delivery, the distance of delivery, etc. As a rule, the participants in the delivery are the sending and receiving parties (medicine specialists) and specialists in delivering (logistic/transportation company).

It is important to provide an opportunity for CDM with partners at a reasonable level of efficiency and balance (minimal risk and maximum safety). This is achieved by fullness, precision, and real-analysis of existing data. Planning of solutions provides using deterministic, stochastic, and non-stochastic decision-making models; methods of dynamic programming and reflexion models. To consider the complexity of the factors that affect the human in the expected and unexpected conditions, a reflexive model of bipolar choice of human has been designed [11; 12; 13]. The result of assessing unprofessional factors is the definition the social-psychological impact on a person's DM by revealing the preferences, diagnostics the individual-psychological qualities of humans during the situation development, monitoring of the human's psycho-physiological factors (emotional state) for early diagnosis of transition to potentially hazardous mental performers and determining stability of patients in working capacity was obtained [11; 12]. In the "*Informational processor of the reflexive intuitive choice*" by human is selected in the directions of *positive pole A, negative pole B; mixed selection AB* according to *reflexion theory* [13]. The choice of human is described by the function:

$$X = f\,(x_1, x_2, x_3\,),$$

where X – is a probability, that a person is ready to choose the positive pole *A* in reality; x_1 – is an environmental pressure on a person towards a positive alternative at the time of choice, $x_1 \in [0, 1]$; x_2 – is the pressure of a person's previous experience on a positive alternative at the time of choice, $x_2 \in [0, 1]$; x_3 – the pressure of a person's desire for a positive alternative at the time of choice, $x_3 \in [0, 1]$.

The general technique of DM by the participants in specific transportation/service/logistic (TSL) is included:

1. Analysis of situation as a complex situation: identification of causal relationships and determination of potential participants of the complex process of delivering medical supplies.
2. Construction of the algorithms of the potential participants' actions in TSL. Determination of the average time of each action for all participants in this situation and the rational sequence of all actions (compilation of a basic structural-temporal table for each participant).
3. Modeling of DM participants' actions in TSL using network planning graphs (Figure 1):
   - Network graph of main technology (instruction) for each participant in the situation.

– The main critical time and critical ways of performance of all action.
– Network graph of main technology/instruction.

If it's model difficult with undetermined decisions (many solutions and wishes) may use the integration of models based on risk and uncertainty DM models.

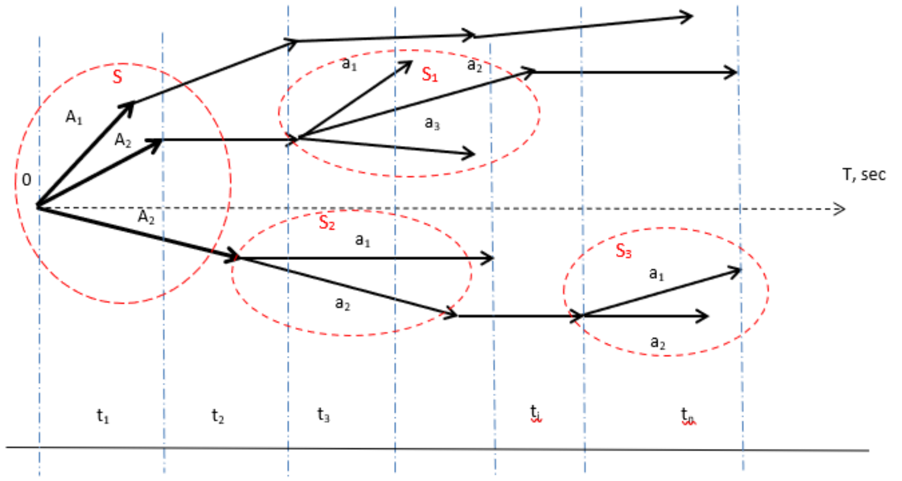

Figure 1: The deterministic models with controversial actions *(S_1, S_2)* of members (A_1, A_2, A_3)

4. Optimization of schedule/plan of performance of main technology and simplification of a complex model (Figure 2). Identification of difficult points where were several alternative solutions and in next using the effective method of DM:
– With the existence of Big Data of the process (experiences, statistic data) are used AI methods for forecasting the responsibility of solutions.
– In a large amount of statistical data and probabilities are used DM methods in risk (Figure 3).
– In the absence of a large amount of statistical data and probabilities, are used DM methods in conditions of uncertainty (Table 1).

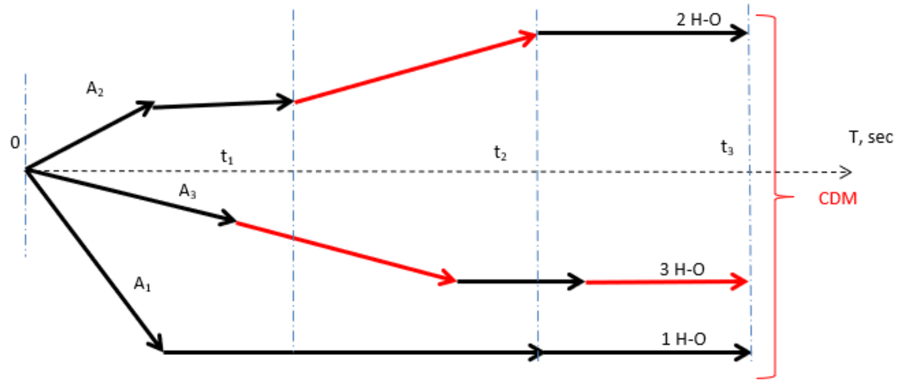

Figure 2: The deterministic models with decisions A_1, A_2, A_3 - simple Network graph

5. DM models in risk conditions: evaluation of risk *R* for different decisions (tool – decision tree). The DM periods are described by decisions ($A = \{A_1; A_2; ..., A_n\}$), a time *t* of the evolution of the situation on each stage, and added value β, that depends on the period of the evolution of the situation and timely DM for countering the situation (Figure 3).

When solving the problem of minimizing the risks during each period, added risks growth ($+\beta_k$), the threats are increasing with time *t*:

$$R_k = t_k \sum_{i=1}^{n} p_i u_i \pm \beta_k,$$

where t_i – is a time of the period k; β_k – is an added risk during the period k; p_i – are the probabilities of the evolution of the situation, $\sum_{i=1}^{n} p_i = 1$; u_i – are the anticipated outputs.

The DM model in risk is shown in Figure 6. Step-by-step correction of the decision matrix is carried out in risk assessment [17].

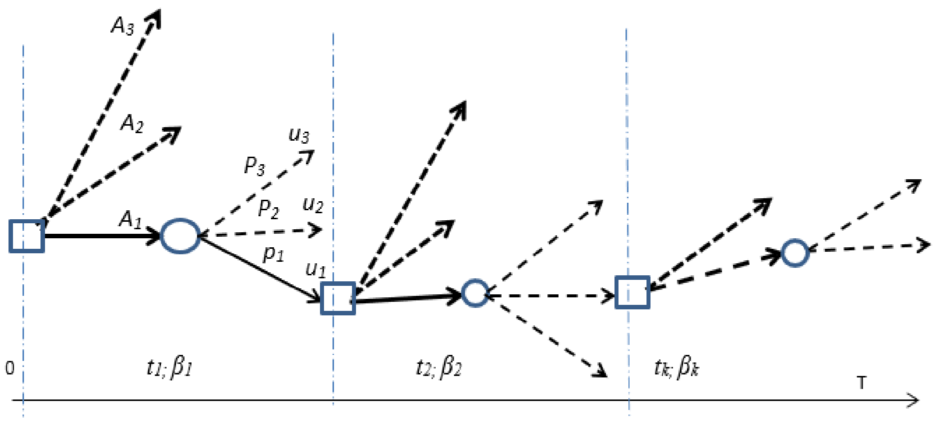

Figure 3: The periods of the evolution of situation and DM on the decision tree

5. Application of the method of the objective-subjective decision in conditions of uncertainty for the formation of CDM.

6. Decision-making matrix under uncertainty for each participant in the process. In the matrix (Table 1), factors are external circumstances influencing decision-making, alternative decisions are possible actions. The optimum decision is found using the criteria of Wald, Laplace, Hurwitz, Sevij - minimum losses and maximum safety during transportation. Each of the criteria has a set of differences in application. The main difference is the different levels of problem uncertainty, types of situations (often, rare, first time), transport opportunities, and complexity of care situation. For instance, the Laplace criterion is based on more upbeat opinions (same situations what were); the Wald criterion is based on more pessimistic opinions and is applied to find the optimum decision for the first moment. The optimism-pessimism coefficient is applied in the Hurwicz criterion that can be adapted in various accesses from the most optimistic to the most pessimistic grade. The Savage criterion is applied for decisions recounting to minimize the losses after completion of the situation.

Table 1

Decision-making matrix in uncertainty for each member

	{A}	*F_1 - objective factors*					*Results according to criteria*			
		f_1	***f_2***	…	***f_j***	…	***f_n***	*Wald*	*Laplace*	*Hurwitz*	*Sevij*
Alternative solutions	***A_1***	U_{11}	U_{12}	…	U_{1j}	…	U_{1n}	F_{11}	F_{11}	F_1	F_{11}
	A_2	U_{21}	U_{22}	…	U_{2j}	…	U_{2n}	F_{21}	F_{21}	F_2	F_{21}
	…	…	…	…	…	…	….				
	A_i	U_{i1}	U_{i2}	…	U_{ij}	…	U_{in}	F_{i1}	F_{i1}	F_{i1}	F_{i1}
	…	…	…	…	…	…	…				
	A_m	U_{m1}	U_{m2}	…	U_{mj}	…	U_{mn}	F_{m1}	F_{m1}	F_{m1}	F_{m1}

7. Decision-making matrix under conditions of uncertainty of all participants in the process. In the matrix (Table 2), factors are the opinions of participants in the transportation process, alternative solutions are joint possible actions. The optimal decision – minimum losses and maximum safety during transportation, taking into account all partners-parties.

Table 2
Decision-making matrix in uncertainty for CDM

	{A}	F_2 - subjective factors						Results according to criteria			
		f_1	f_2	...	f_j	...	f_n	Wald	Laplace	Hurwitz	Sevij
Alternative solutions	A_1	F_{11}	F_{12}	...	F_{1j}	...	F_{1n}	AS_1	AS_1	AS_1	AS_1
	A_2	F_{21}	F_{22}	...	F_{2j}	...	F_{2n}	AS_2	AS_2	AS_2	AS_2
	...			...		...					
	A_i	F_{i1}	F_{i2}	...	F_{ij}	...	F_{in}	AS_i	AS_i	AS_i	AS_i
	...			...		...					
	A_m	F_{m1}	F_{m2}	...	F_{mj}	...	F_{mn}	AS_m	AS_m	AS_m	AS_m

8. Expert system (ES) for assessment of the operability of all types of transport (air, water, land) for solving various intentional goals in urban areas [4; 5].

9. Expert system (ES) for assessment of the operability of UAVs flights (single and group) for solving various intentional goals in urban areas:

1) Assessment of the efficiency of the intentional goals of the next systems applying: a group of individual UAVs controlled by individual operators; UAV group controlled by call detail records (CDR)-UAV; single UAV controlled by one operator. If there is a group of UAVs with control from CDR, then it's necessary:

- Decomposition of the complicated system into subsystems "network topology – intentional goals", a description of the subsystems' specifications, and an assessment of the efficiency of network topologies for execution of the concrete intentional goals.
- The efficiency of the topologies of the network for execution of the intentional goals and determination of evaluation criteria (determination of the appropriate weights for the topology effectiveness).
- Assessment of the efficiency of network topologies of the UAV group for the concrete intentional goals applying Expert Judgment Method (EJM) (determination of the experts' preferences and consistency).

2) Assessment of the urban areas for applying UAVs and methods (GRID analysis of a sectoral UAV flight, fuzzy logic, and EJM for "risk" assessment).

3) Aggregation of subsystems into a new system (additive or multiplicative aggregation, whichever the "intentional goals" type).

4) Graphical performance of the ES results, for example, assessment of the efficiency of the topologies of network for execution the intentional goal "transportation" by UAV group, single UAV or group of single UAVs (Figure 4 To assess the safety of UAV flights in a city, it is necessary to get quantity values of flight risks in various parts of the city.

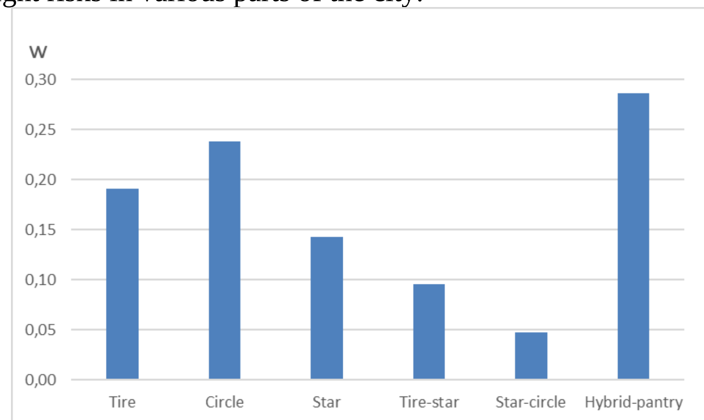

Figure 4: Graphical performance of the ES results, of the efficiency of the topologies of network for execution of the intentional goal "transportation" by UAVs

For example, appraisal and finding the way with the minimal cost W1 for UAV1 in Figure 5, W1=39 for the territory fragment which is depicted in Figure 6.

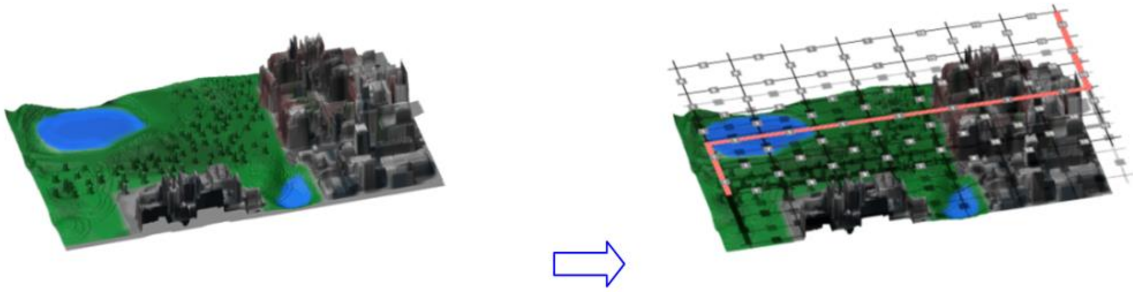

Figure 5: The territory fragment for appraisal of the minimal cost and safety of UAVs motion

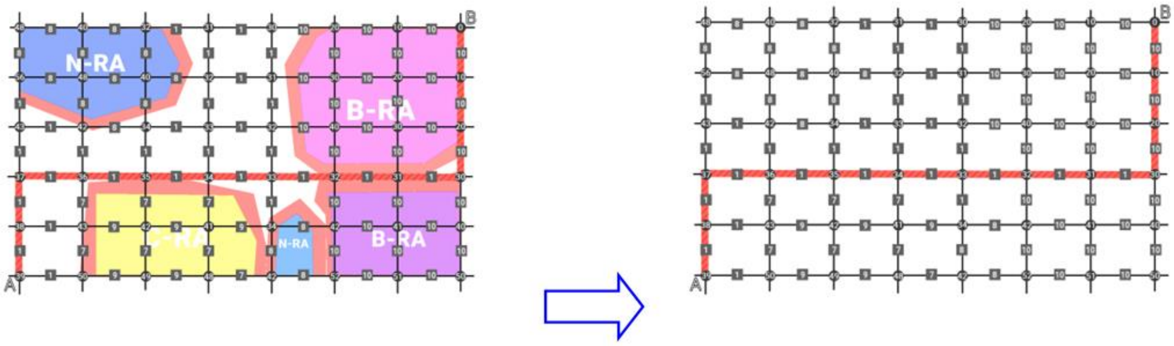

Figure 6: Grid cell risk assessment and calculation of the minimal cost of way W1 for UAV1

The model of synchronization of actions of all participants in the delivery are the sending and receiving parties (medicine specialists) and specialists in delivering (logistic/transportation company) in the difficult conditions can be designed applying artificial intelligence (AI) techniques. The formalization of all participants' actions in TSL with the assistance of AI would allow DM methods to define the optimum subsequence and the time of the performance of the procedure for resolving non-standard situations.

To prepare participants to correct and effective DM action in non-standard conditions, training procedures must be able to simulate situations closely approximating real-life events. The steps in the process of creating such simulated environments are:

- a thorough and deep analysis of the emergency case;
- intellectual processing of data;
- situation identification;
- formalization of the situation with the help of integrated models;
- decomposition of the complicated situation into subclasses;
- synthesis of adapted deterministic models for actions determined by AI.

For example, urgent delivery of medical supplies from the starting point (Uzhgorod) to the terminal point Khust is required. The distance between the cities of Uzhgorod and Khust is about 100 km, mountainous terrain, the UAV delivers urgent cargo before the arrival of the doctor with the minimal cost (Figure 7).

Algorithm of definition minimal cost and maximum safety of UAVs movement ways between towns in next:

1) Grid-analysis - cells are superimposing on a fragment of map (Figure 7).
2) Risk assessment of Grid cells depending on the type of area ("Track area - TA", "Restricted area - RA" or "Dangerous area - DA").

3) Finding the minimum cost path for a UAV1 using the Dynamic Programming method for planning a flight in a first level:

$$W_i(y_i) = y_{i-1}(RA;\ DA;\ TA) + \min\left(y_i(RA;\ DA;\ TA)\right)$$

The minimum cost path is 21 conventional units (Figure 7).

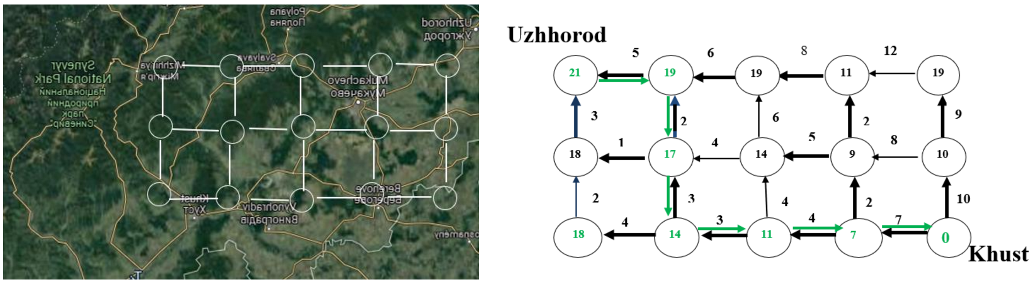

Figure 7: Prototype of hybrid monitoring and situation management system ML-DM

In cases of big and complicated data, techniques can be integrated into traditional and hybrid DM systems of the next generation by processing uncontrolled data of situations in the deep landscape models (Figure 8), potentially with high data transfer and almost in real time, creating a structured presentation of input data by clusters corresponding to the types of general situations [14; 15; 16].

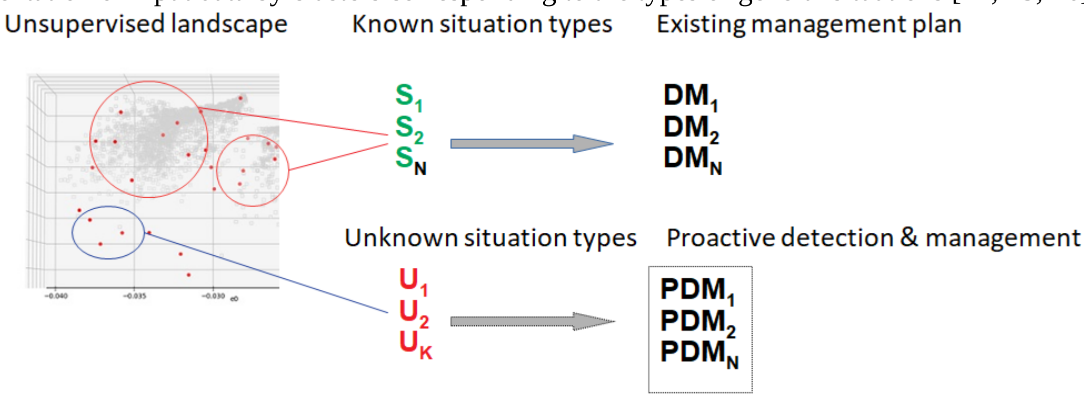

Figure 8: Prototype of hybrid monitoring and situation management system ML-DM

In Figure 8 above, a deterministic model of actions is focused on a concrete type of situation. One more advantage of this model is its potential ability to study to define the interconnections between various types of situations, almost entirely in self-monitoring learning modes with very limited demands to reliable data. Possible uses of these opportunities of models of machine intelligence can spread, for example, on developing the abilities to discover early signs or symptoms of emerging situations through relationships between types of situations, as well as the ability to create notifications and early warnings, which a person can take in advance before the situation develops.

2.2. Experiments & discussions

So, AI is a framework of methods, models, and practices that is capable of performing some human intellectual or physical activities related to the perception and processing of information, reasoning, and DM, communications with natural Intelligence (human), rational support of human in the efforts. These processes of building AI include training (obtaining information and rules for applying the information); reasoning, evaluating, and modeling (applying rules to get approximate or final results); self-correction (assessment of the resulting models); automated systems and human-computer systems; image recognition systems, speech recognition, and machine vision, etc. Particular applications of AI include next systems: Expert systems (ES); Decision support systems (DSS); human-computer systems (HCS);

Automated systems (AS); AI systems. To design and develop an AI system, it is necessary to create an Expert system. An Expert system is an informal model of the system being created, with the help of expert assessment, on small data it's possible to create a demo version of the AI system. The accumulation of data creates a real AI system. Ready-made AI systems have varying degrees of performance and DM. The degree of productivity changes from simple (simple actions) to complex (creative actions):

- simple AI actions - repeating actions;
- complicating AI actions - repeating actions and creating new actions according to existing rules;
- complex AI actions - repeating actions, creating new actions, changing the rules for performing actions;

So, steps for building an AI system:

1. Expert system - a data description information – using experts (according to statistics, experience, skills data too).
2. DM and CDM models – to improve and prepare data.
3. AI systems without training data and effective DM in difficult processes.
4. Big Data to create AI systems with training data and more effective DM /CDM.
5. Big Data to create an AI system with Machine Learning and IDM (Intelligence DM).
6. Big Data to create an AI system with Deep Learning and IDM (Intelligent systems of DM), DM models, models of forecasting of development situations and optimal solutions.
7. Intelligent systems of DM – combine natural and AI – Hybrid DSS.

3. Conclusion

Optimum solutions planning should provide using DM different models such as deterministic, stochastic, and non-stochastic models. After analyzing the situation, it is necessary to synthesize stochastic models to correct an indefinite deterministic model with a set of solutions. A continuous reporting and CDM process is required to synchronize the decisions made by participants and exchange information between them involving natural intelligence and AI as a combined hybrid intelligence for effective DM. It is essential to provide the ability to develop a joint, comprehensive solution with partners at a sufficient efficiency level. The obtained integrated DM and CDM models can be applied in the DSS and ES of physicians to serve patients in future medical AI-based systems.

The example of the transportation medical service situation of patients in healthcare, the search for an optimal solution for effectively delivering medical supplies (with minimal cost and maximum safety) and delivering timely medical care 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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