MULTI-OBJECTIVE DECISION MAKING UNDER CONDITIONS OF UNCERTAINTY AND RISK OF KNOWLEDGE QUANTUM ENGINEERING MEANS

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***Abstract**: Methodology of a complex solution for a problem of decision making under conditions of multi-objective optimization, uncertainties and risk based on the use of mathematical models and knowledge quantum engineering (EKQ) methods is developed.*

***Key words:** multi-objective optimization, utility function, interval scholastic uncertainty, decision making, knowledge quantum engineering.*

Introduction & Setting up the problem

The *decision-making* is an obligatory and an integral problematic stage in the human activity. Independent of the universe of discourse (enterprise, knowledge domain) the general problem of decision-making reduces to solution of the main four problems: 1) *the objective setting up* and *analysis;* 2) *the feasible solutions set generation;* 3) *choice and substantiation of the feasible solutions estimation system (estimation problem);* 4) *definition of the best solution (optimization problem).* The subject making decision (SMD) is always interested in making effective decisions, as ineffective decisions in the vital and productive situations result in considerable losses in possibilities and resources. It is a common knowledge that necessary requirements on *effectiveness* of decisions are their *completeness, timeliness and optimality,* which are conceptually conflicting. The quest for meeting the indicated requirements results in serious methodological and computational difficulties. In particular, the provision of the decision *complexity (completeness)* results in the need for more complete accounting of the internal and external factors, this increases the decision making problem dimensionality and involves its *multi-objectiveness* acknowledgement. In this case the *indeterminacy* rises caused by incompleteness of the knowledge of reciprocal action of factors, inaccuracy of their measurement, random external and internal actions. Attempts to eliminate the initial *indeterminacy* by means of research require a high qualification of a SMD, considerable time and, as a result, involve the decision making *inopportuneness.*

Today the traditional approach does not meet requirements of practice both as to *precision,* and as to *effectiveness* by virtue of the unjustified problem decomposition into two conventionally independent problems. The first problem is the determinate problem of multi-objective optimization is solved without regard for *indeterminacy*, the second problem is the problem of decision making under conditions of *indeterminacy* without regard for *multi-objectiveness.* This is stipulated according to Adamar by the crucial *incorrectness* of the multi-objective optimization problem by virtue of its solution *non-uniqueness.* It is possible to solve the problem correct only to the *compromise* solutions domain or through *regularization* [1, 2]. On the one hand the *regularization* of the problem for defining the *unique* solution through calculation of the generalized *multi factorial* scalar estimate of efficiency is based on the subjective expert estimates, their determination results in considerable errors. On the other hand the models and methods for decision making under conditions of *indeterminacy* of the scalar estimate proved to be inadequate without regard for its *multi-objectiveness.* Consequently, the quest for rising *efficiency* of the decisions being made calls for development of the methodology of the *complex* solution of the decision making problem with continuous regard for *multi-objectiveness* and *indeterminacy* of the initial data.

The state of the problem. The survey and analysis of publications [1-20] point to the urgency of the problem of development of the *formal* models and methods for decision making under conditions of *multi-objectiveness, indeterminacy* and *risk.* The prospects for formalization of the *complex* procedures of decision making with *simultaneous regard for* the indicated conditions are opened when using the *utility theory* [7, 8], *interval analysis* [2, 17] and *fuzzy sets theory* [13, 14, 20]. But the obtained results are still far from exhausting the problem at present. From [2] it is known that *the admissible* set of decisions $Z = Z^S \cup Z^C$ contains in the general case the subsets of *consistent* Z^S and *inconsistent* (*compromise*) Z^C decisions. Not a single local (partial) criterion of efficiency $k_j(z) \in \langle k_j(z) \rangle \subseteq Z^C$ from the *compromises* domain Z^C can be improved without deterioration of the quality if only one local criterion of the specified criteria finite sequence $\langle k_j(z) \rangle$, $j = \overline{1,n}$. According to the definition the sought *optimal* decision $z^* \in Z^C$. That is why the *multi-objective decision making problem* **(MDMP)** can be *formally* presented by the relation

$$z^* = \arg \underset{z \in Z^c}{extr}\, \Theta [\, \langle k_j(z) \rangle], \; \forall j = \overline{1,n}, \tag{1}$$

where Θ is some ***regularizing*** procedure making it possible to choose the ***unique*** decision from the domain of *compromises* Z^c according to a definite *optimality principle.*

Formal approaches to the *regularization* based on some compromise schemes (sub optimization, lexicographic optimization etc.) are known [1, 2]. *Heuristic* principles of the ***regularization*** are often used when the choice of decision in the **MDMP** (1) is realized by a *decision maker* **(DM)** using own experience as a basis [2, 3]. Each of the offered ***optimality principles*** has its own domain of correct practical application and significant shortages [1-3].

The ***principle of optimality*** involving formation of the ***generalized scalar criterion*** on the set of the individual criteria $\{k_i(z)\}$, $i = \overline{1,n}$. It is termed the ***utility function*** $\Pi(z)$ [7 - 9]:

$$\Pi(z) = Q\,[\lambda_i, k_i(z)];\; i = \overline{1,n}, \tag{2}$$

where λ_i are the *isomorphism* coefficients bringing the dissimilar individual criteria $k_i(z)$ to the isomorph form; *Q* is the operator realizing the procedure of the *utility function* $\Pi(z)$ calculation for all $z \in Z^C$. The *utility theory* [8], which assumes existence of the *quantitative* estimate of decisions *preference* « $\succ$ », serves the theoretical basis for the *multi-objective scalar estimates* formation (2).This means that if the solutions

$$z_1, z_2 \in Z^C \text{ и } z_1 \succ z_2 \text{, то } \Pi(z_1) > \Pi(z_2) \tag{3}$$

Consequently, the solutions ***"utility"*** is the *quantitative* measure of their *"effectiveness",* and **MDMP** (1) consists in choosing the *best* decision z^* **:**

$$z^* = \arg \max_{z \in Z^C} \Pi(z). \tag{4}$$

According to (4) *justification for the method* is required for formation of the ***utility function*** as a *metric* in the space of the individual criteria $k_i(z)$. It is characteristic that no ***objective*** metrics exists, and the principle of decisions *ranking* represents ***subjective*** preferences of a **DM.**

Hence, the *utility theory* and the selection of the concrete ***utility function*** in the form of the operator *Q* in (2) bear the *axiomatic nature,* where the *axiomatics* represents *preferences of the concrete* **SDM** or **DM.** That is why the main *hypothesis* for existence of the ***"rational"*** *behavior,* which admits ***reproducibility*** and ***similarity*** of different **DM's** decisions under *identical conditions,* lies at the basis for *the utility theory*. In the frameworks of this *hypothesis* the decisions ranging process formalization helps a **DM** to identify his preferences and estimate *quantitatively* all decisions $z \in Z^C$ through *metrics*. Hereinafter the *estimation procedure* can be realized precisely on this basis using a computer without the **DM** participation. By this means the possibility is achieved to create the *decision making support system* (**DMSS**) of different purpose [1; 2; 10-12; 14 - 16; 18 - 22]. The analysis of these publications attests that the *effective formalization* of finding ***the best,*** in a certain sense, ***multi-objective*** decision is possible only for the *well-structured* problems [1, 2]. Analysis of these publications testify to the fact that *effective formalization* of finding **the best** from the certain viewpoint *multi-objective* decision is possible only for well-structured problems [1, 2]. But in actual practice, *weakly structured* problems are more abundant, the formalized methods are not developed completely for their decision. Thus, the modern tendency of the **DMSS** creation is based on a compromise between a human ability to decide complicated problems and possibilities of formal methods and computer simulation of the *intelligent* activity. Neural networks [14], knowledge engineering expert systems [15] and other systems of the artificial intelligence [10 – 16; 18 - 21] belong to such systems. *Formalization* of the human ***intelligent*** activity in the decision making processes is the general requirement for all these systems. Investigations into this direction are always urgent both for the scientific and practical purposes of automation of the ***imaginative*** work of people.

The objective of this work consists in development of the methodology for solving the problem of the ***knowledge-oriented*** decision-making taking into *complex* account of *multi-objectiveness, uncertainty* and *risk* based on creation of *intelligent* information technologies using the knowledge bit engineering (**KBE)** [10 – 12; 22].

Methodology of decision-making using KBE means. The object in view is reached by solving **MDMP** (1) through the application of the *utility function* of the kind (2) with the operator Q, realized using the **KBE.** Let us use the *systems* approach to the problem of the purposeful decision making based on *knowledge*, the essence of this approach will be set forth in the theoretical-multiple representation. Let us term the set *E* of homogeneous or heterogeneous elements, on which the set of cause-and-effect relations *R* ordering the elements $e \in E$ into the *structure* *C* is specified, as the *purposeful decision making system S* ,:

$$C = \{ E \times R \} \tag{5}$$

To attain the specified ***aim*** the system *S* should offer a set of properties $X = \{x_1, x_2, ..., x_n\}$. Let us map the ***aim*** onto the set ***X*** and single out some subset $G \subset X$ of the system properties, which make it possible to attain the aim through selection and synthesis of its *structure C* (5) with the required properties *G.* Then the *purposeful decision making system S* is defined by the ordered set in the form of the Cartesian product:

$$S = \{\{E \times R\} \times G\} \tag{6}$$

It is evident that the *domain of* $Z(S)$ *existence* of the system *S* with the properties *G* is defined by the set of *structures* *C* (5) which can be find *inductively* under conditions of *uncertainty* and *risk* through the system learning using knowledge-precedents. From *economical, ecological, social and technical considerations* limitations are imposed on the domain $Z(S)$ in the form of prohibitions on the use of some elements $e \in E$ and relations $r \in R$. As a result a set of *acceptable* structures, i.e. *acceptable* decisions of $Z^C \subset Z(S)$, is singled out.

Then the *decision* of **MDMP** of (1) type using **EQK** means is realizable in **4** *stages.* **1**) Definition of the ***aim*** with singling out the properties *X* of the system *S* to attain it. **2**) Inductive synthesis in learning precedents of the acceptable set of structures *C* (5) as ***knowledge bases*** providing the mechanism of decisions logical deduction. **3**) Determination of metric for comparison of the admissible decisions (the *estimation* problem). **4**) Selection of the ***best*** decision version of $z^* \in Z \subset Z(S)$ (*optimization* problem).

Singularity *of* **KBE** *methodology for* **MDMP** (1) decision consists in the synthesis of *S* (6) system by means of the δ **- knowledge quantum base** (**B** δ **KQ**) as a system of the *implicative* and *functional* regularities in the space of X^n *properties* [22], ***inductively*** created at *learning* from the precedents. **B** δ **KQ** has a network structure C (5) of the cause-effect relations between the ***initial*** δ quanta (*message* events), ***intermediate*** and ***output*** δ - quanta (i.e. *goal consequences*- decisions) with the δ - quanta based built-in mechanisms of the ***deductive*** output of the decisions being made. The parameter $\delta \in \{t, \pi, v, \varphi, ...\}$ characterizes the concrete conditions of δ *-uncertainty* and corresponding ***type*** of the used δ -quanta of *knowledge*: ***faithful*** (δ = ***t,*** **tk**-*knowledge*), ***approximate*** (δ = π **,** π **k**-*knowledge*), ***probabilistic*** (δ =**v,** **vk**-*knowledge*), ***fuzzy*** (δ = φ , φ **k**-*knowledge*). For example, **vk**-*knowledge* is used under conditions of **v**-*uncertainty* and ***risk*** as the selection of the alternative decisions is realized on the basis of estimates of the ***probability*** of these or those selection ***consequences*** occurrence**.** It is precisely this **v**-quantum of knowledge contains in its procedure component the built-in algorithms for calculating the *quantum events,* taking into account their cause-effect relations logics. φ ***k-****knowledge* with the built-in algorithms of *fuzzy sets phasefication* and *dephasefication* according to the specified *membership* functions are used by analogy with **vk**-*knowledge* under conditions of φ *-uncertainty* (with ***fuzzy*** data).

Precedents for (**B** δ **KQ**) ***learning*** are described by the *tables of empirical data* **(TED)** and *scenario examples of learning knowledge* **(SELK)** with indication of the names of e_i *–premise,* c_j – intermediate, C_k **–** *purposeful* δ - ***quantum events*** with logical connectives "AND", "OR", "NOT" between events. The process of ***learning*** initially consists in the algorithmic transformation of **TED** and **SELK** ***into the logical net of possible reasoning*** (**LNPR**). Then LNPR is transformed into δ - quantum net for decision output (δ QNDO) through automatic quantification. At the output of δ QNDO there are s δ -quantum vertexes {Ck}={zk}= $\hat{z}$, (k=1, 2,…,s), which correspond to the unique complex $\hat{z} \in Z^C$ of purposeful decisions-effects in MDMP, which depend on the specified premise ei and intermediate cj δ - выходе δ - quantum vertexes-events. Consequently, in MDMP (1) the process of the output of the multi-objective decisions complex {zk}= $\hat{z}$ is realized automatically through B δ KQ $\equiv$ δ QNDO after sending to the input the premises e.i. (i = 1, 2,…,n) describing the observed situations relative to the system object of decision making (ODM). Intensification of the complex $\hat{z} \in Z^C$ of δ -quantum vertexes Ck, (k=1, 2,…,s) at the output of δ QNDO defines the result of purposeful decisions output for the given system ODM.

Efficiency of the ***knowledge-oriented*** *multi-object decisions in the* **EQK** is estimated by the exterior criterion $K_э$($\hat{z}$), which characterizes ***utility*** from the viewpoint of the *minimal* ***risk*** *of negative consequences* of the whole complex $\hat{z} \in Z^C$ of the made ***purposeful*** decisions, generated by δ **QNDO** for the system **ODM.** Estimation of $K_э$($\hat{z}$) can be defined by the value of the ***probability (risk)*** of ***erroneous*** decision making after testing of the given δ **QNDO** on the ***control situations.*** This makes it possible to rank the *alternative* δ **QNDO** by the quality in the indicated sense from the general region of $Z(S)$ existence. The ***rational*** *complex* of solutions $\hat{z}_{рац} \in Z^C$

generated by δ **QNDO** with the *least* value of the estimate ***K***$_э$($\hat{z}$) is considered to be ***the best*** ones. The essence of the **MDMP** (1) solution by steps consists in the following.

In the **1st** ***stage*** the ***aim*** of *S* (6) system is defined as some ***desirable*** state of the systems **ODM,** its accomplishment requires purposeful actions. In our case the ***aim*** consists in the ***inductive*** *synthesis with irradiation of* **B**δ **KQ**$\equiv \delta$ **QNDO** which ensures derivation of the *complex* {z_k}**=** $\hat{z} \in Z^C$ of the ***purposeful decisions*** C_k for the whole systems **ODM** . Experts single out the *particular* functional *properties* $X = \{x_1, x_2, ..., x_n\}$, required to attain this aim, which are measured in scales of *different types* and define potential *efficiency* of the system *S*. Hence, the *properties X* are the *local criteria* for estimating *efficiency* of the decisions being made, and the ***problem*** (1) being considered is the ***multi-objective*** one, as the ***aim*** is characterized by a set of *particular* criteria *X.*

In the ***2nd stage*** the experts together with DM substantively form **TED** and **SELK** needed for the synthesis of the *purposeful* **LNPR** in the learning mode. **LNPR** transforms through *automatic* ***quantification*** into δ **QNDO,** the sets of *acceptable* decisions $\hat{z} \in Z^C$ of the **MDMP** (1) problem are defined with its help. It is possible to form several versions of TED and SELK for synthesis and learning of the *totality* of different δ **QNDO** on the *precedents* of different types with the aim of the further *rational* version of δ **QNDO** choice**.**

In the ***3rd stage*** the problem of ***estimating*** is solved, i.e. some ***measure*** is defined making it possible to compare objectively the efficiency of *complexes* of solutions $\hat{z} \in Z^C$ between themselves and, hence, estimate ***quality of*** δ **QNDO** generating $\hat{z}$ under conditions of *multi-objectiveness,* ***risk*** and δ ***-uncertainty*** ($\delta \in \{t, \pi, v, \varphi, ...\}$). Such a ***measure*** should take into account both a *positive* ***effect,*** i.e. the stage of the ***aim*** attainment, and ***expenditures*** for attainment of this effect. The concrete expenditures for creation of the system *S* (6) also requires a synthesis of any version of the structure *C* (5) which is realized by the net δ *-quantum* graph $G_{\delta k} \equiv \delta$ **QNDO.** On the ***output*** $G_{\delta k}$ the *complex* of the required solutions {C_k}= $\hat{z} \in Z^C$ is obtained after activation of the *message* δk -knowledge e_i on the graph ***input***. This makes it possible to apply the ***model*** $\Phi(\hat{z})$ of the ***informal*** *multi-objective* estimation of *decisions* ***efficiency,*** available in **KBE,** by the value of the ***probability*** of *unfavorable* ***consequences*** of the *decisions made* with the use of the outer criterion $K_э(\hat{z})$:

$$\Phi(\hat{z}) = Q[K_э(\hat{z});\ \delta KCBP;\ B_j],\quad (j = 1, 2, ..., s) \tag{7}$$

Model (7) is presented by the *operator mapping* $\Phi(\hat{z})$ for definition of the ***utility*** of the *complex* of ***purposeful*** decisions $\hat{z} = \{C_1,...,C_s\} \in Z^C$ by the specified methods of the algorithmic calculation of the $K_э(\hat{z})$ *efficiency* estimation. This *mapping* is realized by the *operator* Q, which characterizes the structure of the model $\Phi(\hat{z})$ taking into account the *procession* of *parameters* B_j, kind of dependence between *input* and *output* **B**δ **KQ** $\equiv \delta$ **QNDO** and provides generation of $\hat{z} \in Z^C$ with calculation of the value of $K_э(\hat{z})$ ***risk*** to make ***erroneous*** decision in *control* situations.

The concept of informal multi-objective estimation of the decisions being made in EQK is based on the universally adopted verified in practice confidence in professional knowledge and experience of specialists in the problematic domain, when choosing the alternatives without evident multi-objective formalization of the choice. As professional knowledge and experience of experts admit the δk -knowledge formalization in the form of a special Bδ KQ$\equiv \delta$ QNDO [10, 22] it is possible avoid the known difficulties of the explicit formalized synthesis of the generalized criterion for aggregating of the local criteria when estimating the decisions efficiency. With this aim in view it is sufficient to estimate utility of the found final totality Bδ KQ$\equiv \delta$ QNDO under concrete conditions of δ -uncertainty and risk with the help of the Kэ($\hat{z}$) external criterion reaching the *minimal* ***risk*** of the ***erroneous*** decision making in the control situations. In this case the model $\Phi(\hat{z}\ )$ (7) fits the axioms of the selection theory under conditions of ***risk*** of von Neuman and Morgenstern [7, 8] and is proper for estimating efficiency of the *knowledge-oriented* decisions simultaneously under ***complex*** conditions of *multi-objectiveness,* δ ***-uncertainty and risk.*** Contrary to the *polynomial approximation* of dependence (7) known from [1, 2] in EQK it is used δ ***-quantum*** graph $G_{\delta k} \equiv \delta$ **QNDO** described by the *generalized* s*-value* predicate P ($G_{\delta k}$) in the form of *disjunction* s *of Boolean* functions $F_i(\varphi_i(\tilde{x}_j), \tilde{B}_i)$, ($i$=1,2,..., s). The number *s* of purposeful decisions (***C₁,…,Cₛ***)$\in \hat{z}$ defines *s-digit* of the generalized predicate P($G_{\delta k}$). The functions $F_i(\varphi_i(\tilde{x}_j), \tilde{B}_i)$ fit δ -*quantum path* of the graph $G_{\delta k}$ and describe logical *cause-effect reasoning* in δ **QNDO** relative to *s* ***purposeful*** decisions-***effects*** $C_1,\ldots,C_s$ in the complex $\hat{z}$. In this case the parameters $b_i \in B_j$ of the model $\Phi(\hat{z})$ are defined with an accuracy of the *interval uncertainty*, this is stipulated by the diversity of the *experts'* judgments when forming **SELK.** The *interval uncertainty* means that only boundaries of the interval $[b_i^{\min}, b_i^{\max}]$ of the possible values of parameters b_i are known. The values α_k^j of indications $x_j = (\alpha_1^j, \alpha_2^j, ..., \alpha_{\rho_j}^j)$, $(j = 1, 2, ..., n)$ of **ODM** also can be specified by the boundaries of the intervals because of so-called **NOT-***factors* (*incompleteness* of knowledge, *inaccuracy* of measurements etc.). In this connection all ***interval*** values used in δ ***-****uncertainty* are symbolized by «~».

Thus, separate ***complex*** of solutions $\hat{z} \in Z^C$ in **MDMP** (1) represent the ***net system*** of the logical derivation *s* of ***purposeful consequences*** in the form of δ **ODM** which is described by ***disjunction*** of Boolean functions $F_i(\varphi_i(\tilde{x}_j), \tilde{B}_i)$, ($i$=1,2,..., s), depending on two-valued predicates $\varphi_i(\tilde{x}_j)$ and procession of parameters $\tilde{B}_i$, characterizing, respectively, ***meaning*** and ***quantity*** of δ ***-****quantum* vortex- ***events*** with logical connections between them. The predicates $\varphi_i(\tilde{x}_j)$ describe the ***logic of cause-effect*** connections between *local criteria-***properties** $k_j \equiv \tilde{x}_j$, $(j=1,2,...,n)$ of **ODM**. Hence, the ***model*** $\Phi(\hat{z})$ (7) for estimation of the *knowledge-oriented* solutions under conditions of ***multi-objectiveness, risk*** and δ ***-uncertainty*** can be written as:

$$\Phi(\hat{z}) = Q[K_э(\hat{z}); \quad \bigvee_{i=1}^{S} F_i((\varphi_i(\tilde{x}_j), \tilde{B}_i)] \tag{8}$$

In the ***4th stage*** the choice of the unique *rational* decision $\hat{z}_{рац} \in Z^C$ the from the admissible set Z^C is realized on the use of the ***2nd stage*** and the model (8) results. Then, according to the formulas (4) and (8), the problem (1) is specified, i.e. **MDMP**, obtains the following formal form in terms of the knowledge quanta engineering:

$$z^* = \hat{z}_{рац} = \arg\min_{\hat{z}\in Z^C} \Phi(\hat{z}) = \arg\min_{\hat{z}\in Z^C} [Q(K_э(\hat{z}); \quad \bigvee_{i=1}^{S} F_i((\varphi_i(\tilde{x}_j), \tilde{B}_i))] \tag{9}$$

The concept "*rational*" decision is more reliable here than the "*optimal*" one by virtue of the *informal-multi-objective* motivation of the offered metrics (8) for estimation of the decisions being made under ***complex*** conditions of *multi-objectiveness,* δ *- uncertainty* and *risk.*

Results of the **EQK** presented methods computer realization [10 – 12; 22] confirm its efficiency and advantages over the available approaches when solving many practical decision-making problems in different conjectural domains.

Conclusions.

1) The methods are developed on the basis of **EQK** means application and *intelligent* information technologies for solving the problem of *knowledge-oriented* decision making with a *complex* consideration of *multi-objectiveness,* various types of δ - *uncertainty* ($\delta \in \{t, \pi, v, \varphi, ...\}$) and *risk*.

2) Contrary to the available approaches the offered **EQK** methodology ensures the *cause-effect inference* of efficient *multi-objective* decisions under different conditions of δ ***- uncertainty*** and ***risk*** at the expense of δ ***к-****knowledge* in the model of *informal-multi-objective* estimation of alternatives through *external* criterion according to their ***utility*** in terms of any preferences of **DM** without resorting to the synthesis of the *generalized* criterion with weighting the *local* criteria.

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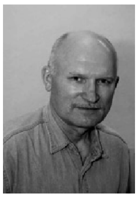

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