Models, Methods and Technological Usage of Expert Knowledge Formalization for Strategic Decision Making under Deep Uncertainty

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Abstract

The paper aims at Expert Knowledge formalizing and technologically using for Proactive Anti-crisis Strategic Decisions making under deep uncertainty within dedicated Expert-Analytical Methodology named DMDU EAM. DMDU EAM benefit is no essential resource demands while keeping the basic principles to deal with deep uncertainty (uncertainties and inconsistencies eliciting; Decision vulnerabilities searching instead prediction; Decision resilience against threats prior its effectiveness).

Knowledge operation is enabled with DMDU EAM procedures such as formal analysis, individual expert assessment, Decision elements deliberative forming. Domain Ontology–based common information space ensures equal participants' awareness, expert judgments and their arguments constructive representation and knowledge reuse. Expert-analytical Proposals Selecting uses their Perspectivity Model. It is a sub-goals hierarchy where the nodes are represented with ontologically formalized definition for State of the Art corresponding sub-goal achievement. Leaf node depicts State of the Art with explicit expert Estimates of Certainty factor (from the Stanford algebra) being provided concerning its implementation through Decision element Proposal being assessed. Perspectivity Model also contains conditions for goal achievement violation being caused with environmental threats. Procedures for Estimates formal integration up to the Model provide extreme estimates of Proposals Perspectivity and Robustness regarding current uncertainty. Under unsatisfactory properties of integrated Estimates their deliberative adjustment is carried out using Uncertainty Map and arguments provided. The final reference Decision contains selected Goal-Means option and Recommendations to adapt it when Decision frame changes.

EAM DMDU enables Deliberative multi-staged Process for Adaptive Decision forming aimed at expected future Crisis situation resolving. Further research is carried out for EAM DMDU instrumental tools development and its usage for defense resource management.

Keywords

Anti-Crisis decision, deliberative estimates adjustment, decision vulnerability, deep uncertainty, Stanford certainty factor algebra, expert-analytical methodology, uncertainty map, estimate argumentation

1. Problem statement

Decision-making under deep uncertainty (DMDU) Support is one of the most critical challenges of modern Strategic Management theory and practice.

Deep uncertainty that has to be coped within modern Organizational Management Systems (OMS) is represented [1] with options high multiplicity or even absence ([2] IVA and IVB levels) of knowledge about such Decision Space elements as the world's Future State; the System being

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prospectively impacted Model; impact Outcomes; these Outcomes' importance within various stakeholders Views.

Basic methodological decision-making trends within DMDU problem area are Robust Decision Making [3], Dynamic Adaptive Planning [4] and Dynamic Adaptive Policy Pathways [5]. They can be referred to as global methodologies because consider the possible states of the world broadest range.

In modern OMS rapid and non-anticipated changeability of Factors and Priorities as well as multi-vector Interests to be considered contribute drastically in Strategic and Proactive Decision making concerning anti-crisis measures and development opportunities capturing.

But high requirements that basic DMDU Methods pose to the Repository being created with model experiments results make these Methods troublesome under resource limitations in place most of the time. That's why borrowing underlying Principles of DMDU Methods above (being elaborated for the State and International management levels – defense planning, climate change anticipation etc.) is of vital importance for dedicated Methodology elaboration that is resource-friendly for smaller-scale OMS with limited capabilities.

The paper presents a variant of such Methodology entitled DMDU Expert-Analytical Methodology (DMDU EAM) as a compromise approach capable foundational DMDU principles to borrow but with the emphasis shifting from the above Decision Space global modeling to professional knowledge and experience of high-skilled domain Experts effective involving.

DMDU EAM does not aim at global approaches full-fledged replacement. It does not provide proved properties of Decisions and sets essential requirements for Expert skills, especially at the stage of basic models preparing for further reuse.

It benefits with:

1. Handling various types of uncertainty;
2. Capturing all Proactive anti-crisis Decision life cycle stages – from Problem Situation analysis to Reference Decision adjustment for operational situation;
3. Meeting DMDU foundational principles including:

- Uncertainties and inconsistencies eliciting and specifying;
- Shifting the emphasis from the future predicting to vulnerabilities searching for Decision being made with respect to possible threats from the future;
- Searching for Decision options that are the most robust with respect to threats regarding all essential aspects of its effectiveness;
- Preventive impacts elaboration on external environment for risks mitigation of possible threats.

A particular aspect of the Methodology proposed is a Deliberative expert process [6, 7] implementation including Experts presenting various viewpoints on Decision problem area.

The standardized DMDU process being proposed and structured in [1] to compare the various methods being developed combines the stages as follows:

- Process architecture defining with respect to adaptation mode;
- Alternatives and future scenarios exploration;
- Robustness analysis;
- Vulnerability analysis.

Table 1 compares DMDU EAM with global methodologies based on solutions for these steps.

Table 1
DMDU EAM description comparing with global approaches

DMDU EAM Aspect	Global methodologies' Support	EAM DMDU Support
Enabling Adaptivity	Contrasting Adaptivity Paradigms: Protective (protect basic plan against contingencies) vs. Dynamic (sequencing of alternatives conditional on observed future)	Providing the most promising policies among those being considered with guides to adapt them when adjusting information undetermined at their elaborating stage
Uncertainty	Uncertainty connected with the	Specifying various uncertainty types

DMDU EAM Aspect	Global methodologies' Support	EAM DMDU Support
manifestations and handling	future. Policies efficiency modeling under all possible states of the world (scenarios)	regarding Decision implementing conditions, alternatives parameters and results of decision making process interim stages. Expert assessment of Alternatives perspectivity under the worst and the best parameter values
Problem statement forming	Determining the scenario space basis and multi-component policy efficiency model	Alternatives considering for both impacting goals and their achieving means. Alternatives Perspectivity defining based on state of the art hierarchy for which Expert confirmations or refusals of reachability under conditions given with current uncertainty determine Certainty factor in Decision objects' target state providing with given Alternatives implementing
Alternatives analysis	Efficiency assessment or choice based on efficiency – over the entire scenario space or critical zones being elicited	Alternatives Perspectivity assessment (optimistic and pessimistic) with considering an option to adjust conditions of current evidences'' sufficiency loss for hypothesis certainty factor assessment Considering threats that cancel inputs of some nodes within state of the art hierarchy
External threats eliciting for internally provided Alternatives effectiveness	"Red Teams" [8] best practices exercising with the proper goal trees for further scenario space updating with the threats elicited	External threats and enabling factors from the Decision frame eliciting with Critical System Thinking methods [9]. Representing threats within the Robustness model that thus enhances the Perspectivity model
Alternative Robustness	Being evaluated: as efficiency loss minimum with respect to a given efficiency basic level under some state of the world or as the number of world's states where given efficiency threshold is achieved for alternative	Evaluated for alternatives, whose expert assessment of the prospects of a thing is beyond the threshold value, as the savings of the prospects in case of influx of threats for the obvious non-obviousness of the situation, the Decision and the parameters of the alternatives
Threats Analysis	Scenarios characteristics finding that are critical for uncertainty impact Critical areas identifying within the spaces of policies and states of the world	Using Information Uncertainty Map and properties of decision-making process interim stages' outputs for guides obtaining towards further adaptation
Participation	Expert involvement for experimental data analysis outputs interpretation without	Formal procedures using for Expert judgments integrating and aggregating with diagnostics of the consistency level

DMDU EAM Aspect	Global methodologies' Support	EAM DMDU Support
	procedural regulations	being achieved acceptability and potential sources of inconsistencies. Passing to deliberative procedures using the interactions protocol and argumentation formats being provided when it is required

2. EAM DMDU General Description

The methodology purposes at supporting deliberative multi-stage PD Process of an adaptive Decision forming, aimed at the Crisis situation anticipating in the future to resolve. The process model looks like the tuple

$$MPD = < I, \{ < KD, MST(KD) > \}, MUI, WUI, \{MEt_i\}_{i=1}^{6} >, \qquad (1)$$

where I is the common information space; KD is Decision type; $MST(KD)$– problem statement model for KD-typed Decisions; MUI, WUI are information uncertainty model characterizing data from I that PD process uses and, respectively, selected modes of uncertainty handling within the Process stages' procedures; MEt_i is the model of i-th PD Process stage – one of its ten subsequent stages. These are as follows: Problem situation analysis; Goals proposing for Problem situation to impact; Assessing the goals Proposals provided; Measures proposing to achieve the Goal adopted; Assessing the measure Proposals provided; Reference variant selecting and adaptation options analysis.

The structure of common information space I is characterized with such a tuple:

$$I = < OM, O, \{DS\}, \{SM(KD)\}, P, PM > \qquad (2)$$

where OM is an ontological model for OMS Decisions problem area; O is the list of objects being processed during PD process stages; DS are information sources that could be used for objects O states identifying; $SM(KD)$is a frame model for a Decision with given type that identifies ontology concept essential for procedures P from MEt_i based on the previous expertises retrospective data and activity experience; P are the procedures for State of the Art concerning given objects O formal identifying based on $\{DS\}$; PM are the procedures for $SM(KD)$ models interpreting based on DS information.

An ontological model

$$OM = STR \cup ACT \cup ENV \cup INT \cup PL \cup DEC \qquad (3)$$

combines inter-referenced ontologies characterizing various OMS aspects: components and structure (STR); activity (ACT); factors of activity external environment (ENV); external stakeholders interaction (INT); goals, priorities and planning programs (PL); strategic and operational Decisions (DEC)..

The model is based on dedicated knowledge conceptualization [10].

It provides for all the concepts CE_{BAS} from the stage models MEt (See (1)) their ontological definitions

$$Def(CE_{BAS}) = \{(R_i, CE_i)\}_{i=1}^{N_{BAS}} \cup \{PAR_K(CE_{BAS})\}_{k=1}^{M_{BAS}} \qquad (4)$$

where CE_i is a concept from OM not belonging to CE_{BAS}; R_i is a relation linked CE_{BAS} and CE_i; PAR_K is a concept CE_{BAS} parameter with the values range $Z(PAR_K)$; N_{BAS}, M_{BAS} is the number of the above CE_{BAS} properties.

Object $O(CE_{BAS})$ that is an information element of stage model MEt interpretation for a specific Decision is defined as $INT(Def(CE_{BAS}))$ interpretation:

$$\forall i \in (1, N_{BAS}) INT(CE_i) = O(CE_i) \qquad (5)$$

$$INT(R_i) \in (0,1); \forall i \in (1, M_{BAS}) INT(PAR_K) \in Z(PAR_K)$$

where $ST(R_i) = 0$ means that object $O(CE_{BAS})$ has not the property mentioned.
The state of object O at a fixed moment t

$$S(O,t) = INT_t\,(Def(CE_{BAS})) \qquad (6)$$

is thus defined through the states at moment t of those objects and relations that constitute CE_{BAS} properties and also current values of their parameters.
Based on (4)-(6) one could define the Sate of the Art for the set of objects $\{O\}$ at moment t $SS(\{O\},t,DS_a)$ being informationally confirmed as follows:

$$S(O,t) = INT_t\,(Def(CE_{BAS})). \qquad (7)$$

Informational DS_a - confirmation is made with the P procedure from (2) or with Expert statement by means of mapping

$$(\{O\},\{DS_a(t)\},) \rightarrow \{S(O,t)\} \qquad (8)$$

where $DS_a \subseteq DS$ is a subset of information sources representing data concerning objects O.
Procedure PM from (2) semantics is given with the mapping

$$PM:(SM(KD),dec,t,DS_{dec}(t)) \rightarrow ISM(dec,t) \qquad (9)$$

where SM is the Decision Frame model for KD-typed Decisions with the composition of $SM = \{C \mid C \in OM\}$ corresponding the subset of ontological model concepts representing current conditions for those Decisions making and implementing stages; dec is a KD-typed Decision; t is a time moment; $DS_{dec}(t) \subseteq DS$ is a subset of information sources containing information about the state of $Def(dec)$ objects valid at t moment; $ISM(dec,t)$ is a State of the Art $SS(\{OI\},t,DS_a)$ concerning the set of objects OI that interpret SM according to the rules (5).
The Problem Statement model from (1) looks like

$$MST(KD) = < MCR, \{< CTR_i, CP_{i,} CONT_i >\}_{i=1}^{6} >, \qquad (10)$$

where MCR is an anticipated crisis model:

$$MCR = < CCr, ICr, SCr >,$$

where CCr is a set of those ontology concepts that their states interrelations constitute an anticipated crisis contradiction; ICr are information sources to CCr characterize; SCr are ontologically specified States of the Art being considered as crisis symptoms; CTR_i are acceptance conditions of i-th stage results; CP_i are the requirements for the stage expert group; $CONT_i$ is an information context recommended for the stage.
The structure of the stage model from (1) is as follows:

$$MEt_i = \{E_{ij}\}_{j=1}^{10}, \qquad (11)$$

where the j-th type of i-th stage element E_{ij} is as follows: E_{i1} – output information structures from (1), (2), (10) models and the previous stages results; E_{i2} – an information context; E_{i3} – Expert judgment structure and argumentation reference model; E_{i4} – procedures for source data automated preparing; E_{i5}– procedures for Problem Statement and Expert judgments reference model deliberative enhancing; E_{i6} – procedures for individual expert judgments providing and arguing support; E_{i7} – procedures for expert judgments formal integrating and aggregating; E_{i8} – the stage result and its properties; E_{i9} – Information Uncertainty Map for the result; E_{i10} – procedures for commonly acceptable result deliberative forming with iterative identifying of 8th and 9th element types.

3. Perspectivity and Robustness Models of Decision Element Proposal

The tools for knowledge (related to various aspects of Decision problem area and pertaining to various sources and holders) interaction, alignment and agreement are proposed to be dedicated Models of Decision element Proposal, namely its Robustness with respect to external threats and Perspectivity.

With these Models Proposals are considered for two Decision elements such as the Goal of Problem Situation impacting (Res_3 within Et_3 stage model) and the Way to achieve this Goal (Res_5 within Et_5 stage model), See (11).

Let's define the result of decision *dec* (modeled with (1)) making process completed at time moment t as a sequence

$$\{\overline{Res_i}\}_{i=1}^{6} \quad (12)$$

where $\overline{Res_i}$ is E_{i8} element of the *i*-th stage model (see (11)), considered as $SS(O_{i8}, t, PR)$ (See (7)), $PR \in \{DS\}$ – decision execution protocol i $\forall o \in O_{i8}$ $o = INT(Def(\mathrm{Res}_i))$ (See (5)).

The perspectivity $PER(AL_{ij}, EX_k)$ of *j*-th Proposal AL_{ij} being considered over *i*-th stage within expert EX_k knowledge is defined as the level of certainty

$$CF(H_O \mid Arg(EX_k)) \quad (13)$$

for hypothesis

$$H_o : (\overline{Res_i} \rightarrow \overline{Res_{i-2}}) \quad (14)$$

based on argumentation given by the Expert EX_k.

The perspectivity model $MPERS_i^{KD}$ (*i* – stage number, *KD* – Decision type) constructively clarifies its representation (13) using the Stanford fuzzy inference method based on certainty factor [11].

Let's define the facilitation ratio $RH(X_1, X_2)$ between the States of the Art X_1, X_2 with the metrics of certainty factor for the hypothesis

$$X_1 \rightarrow X_2 \quad (15)$$

$X_1 = SS(O_1, t_1, D_1)$; $X_2 = SS(O_2, t_2, D_2)$; $O_1, O_2 \subseteq ISM(dec, T)$ (See (9)); T is the period Decision making; $t_1, t_2 \in T$; D_1, D_2 – information sources from $\{DS\}$ in (2).

The Perspectivity model is proposed to be the tuple

$$MPERS = < PER, \{< A_j, TR_j >\}_{j=1}^{N}, Sc > \quad (16)$$

where PER is an integral perspectivity indicator corresponding the target State of the Art; A_j – *j*-th perspectivity aspect related with *k*-th ontology from (3); TR_j is the States of the Art hierarchy that specializes aspect A_j as a sub-goals tree for target State of the Art achieving where the elements are in turn represented as the States of the Art for corresponding objects; Sc is a verbal scale used to evaluate both PER and other model nodes as certainty factor [11] for corresponding State of the Art.

The scale is characterized in table 2.

Table 2
Scale divisions for certainty factor assessing relating to given State of the Art implementing

Division description	Weight
Absolute denial	-1
Credible denial	-0.7
Essential denial	-0.3
Uncertainty	0
Essential confirmation	0.3
Reliable confirmation	0.7
Confirmation guaranteed	1

In (16)

$$TR_j = < NDI_j, NDL_j, CL_j > \quad (17)$$

where NDI is a set of intermediate nodes $\{ndi\}, ndi = SS(O, t, D)$; NDL is a set of leaves; CL is a set of bushes.

A leave is represented with a triple

$$(ndl \in NDL) = < S, CON, EB_{ex} >$$

where S is the State of the Art for which a direct expert assessment of certainty factor is possible with Sc scale based on both the recommended context $CON \in ISM(dec,T)$ and the individual context EB_{ex} provided by Expert ex based on his domain experience.

In turn, within (17)

$$(cl_k \in CL) = < ndi_{r,s1}, \{nd_{(r-1),s2}\}_{s2=1}^{S}, CF_k >$$
$$(nd_{(r-1),s2} \in (NDI \cup NDL)) \wedge RH(nd_{(r-1),s2}, ndi_{r,s1})$$

where $ndi_{r,s1} \in NDI$ is the root of a bush; nd is a node of the bush that specifies a State of the Art satisfying the condition (See (15)); S is the nodes' number; CF_k is an optional element of cl_k definition setting the condition

$$CF_k(\{e \mid \in ISM(dec,T) \cup def(ALT)\}), \tag{18}$$

formalizing the set $\{nd_{(r-1),s2}\}_{s2=1}^{S}$ non-validity as the rational for the estimate of certainty factor related to hypothesis regarding the State of the Art $ndi_{r,s1}$.

The perspectivity model thus defined with (16) – (18) is assumed to be elaborated beyond the PD Process (1) for further multiple reuse concerning certain class of Decisions (specified with ontological classes of concepts from the Crisis model within (10) and/or the measures proposed class).

An individual expert estimate of certainty factor being provided during PD Process (1) for a $MPERS$ leaf L_i by Expert E_k concerning the Proposal AL_j is a triple

$$EAS_{ijk} = < AS_{ijk}^{OP}, AS_{ijk}^{P}, Arg_{ijk} > \tag{19}$$

$$Arg = \{D_E, O_{CH}, ONTK(O_{CH}, AL), < UI, Z^{OP}, Z^{P} >\} \tag{20}$$

where AS^{OP} and AS^{P} are both the estimates up to Table 2 scale corresponding the most and respectively the least appropriate meanings of CON and EB from (17) elements being incompletely defined; Arg is the argumentation; D_E is a context element being used; $O_{CH} \subseteq \{O\}$, O is pertinent to the State of the Art L_i definition; $ONTK$ denotes the ontological relationships determining the elements interdependencies used by Expert; UI is D_E's information uncertainty type; Z^{OP}, Z^{P} are respectively the best and the worst D_E's suitable meanings.

Individual estimate of integral perspectivity indicator PER from (16) is proposed to obtain through estimates EAS_{ijk} (19) integrating under k, j being fixed up to the rule [12] of certainty factor estimates multiplying for the set of independent evidences of the same hypothesis validity.

For the root ndm of a bush with S leaves being estimated with $\{AS_i\}_{i=1}^{S}$

$$AS_m = ((AS_1 * AS_2) * AS_3) * \ldots) * AS_S) \tag{21}$$

where operation $*$ semantics is as follows:

$$AS_{S1} * AS_{S2} = AS_{S1} + AS_{S2} - AS_{S1} \cdot AS_{S2},\ AS_1, AS_2 > 0$$
$$AS_{S1} * AS_{S2} = AS_{S1} + AS_{S2} - AS_{S1} \cdot AS_{S2},\ AS_1, AS_2 < 0$$
$$AS_{S1} * AS_{S2} = (AS_{S1} + AS_{S2}) / (1 - min(|AS_{S1}|, |AS_{S2}|)\ \text{otherwise}$$

Those Proposals being evaluated for which at least one optimistic expert estimate of integral perspectivity indicator under 0.3 or no its pessimistic estimates over 0.3 is obtained are eliminated from further considering as unacceptable.

Considering nd_m as a node of an interim bush rooted with nd_{m-1} and using its estimate obtained AS_m the estimates of interim root nd_{m-1} are further calculated and so on in such a way up to the root A_j of the tree TR_j and finally – an individual estimate of integral perspectivity indicator PER for AL_j Proposal.

Performing the above described procedure twice – for both optimistic and pessimistic estimates of all the nodes of the Perspectivity model (see (19)) – provides the pair of estimates

$$< AS_{jk}^{OP}, AS_{jk}^{P} > \tag{22}$$

An input of CF_S into the estimate AS_{jk} due conditions violation of the evidences sufficiency for the s-th bush root (18) is calculated in such a way.

During integrating the direct leaves' estimates according to the rule (21) CF_S validity is verified under the current values of its operands (18). Validity confirmation provides for nd_S an input 0 regardless of the bush nodes estimates.

The estimates AS_j^{OP}, AS_j^{P} (being the results of corresponding individual estimates (22) generalizing through averaging with respect to Experts list) are proposed to further subject the procedure of collective Expert approval. In case of objections and/or inconsistencies the deliberative procedure is performed based on the principles of iterative Delphi process proposed earlier in [13] and estimates' argumentation elements (19), (20) considering.

The Perspectivity model (16) – (18) could be enhanced with external threats specification that cancel the node ndm of the tree Tj from (16) validity as an evidence concerning the certainty factor of predecessor node. The corresponding specification is represented with the tuple:

$$< \{THF_{mr}, \{F | F \in OM\}, C_r(\{SS(F,t,\{Arg_{ik}\}_{k=1}^{K}\}_{r=1}^{R}) > \tag{23}$$

where THF_{rm} is the r-th threat to ndm node being an event not necessarily pertain to OM ontology; $F \in SM$ is a factor influencing THF_{rm} actualization; t is a time moment; Arg_{ik} is an argumentation provided by the Expert k for i-th leave assessment serving as an information source about State of the Art concerning F_r factor; C_r is a condition of F_r actualization.

Then the estimate of integral perspectivity indicator PER from (16) for AL being calculated with considering CF conditions could be modified by assigning the value –1 to all the nodes ndm satisfying at least one of C_r conditions.

Let's denote $PER_{jk}^{OP}, PER_{jk}^{P}$ and PER_{jk}^{*OP}, PER_{jk}^{*P} the estimates of AL_j Proposal by k-th Expert, integrated without and, respectively, with considering C and CF conditions.

Then the robustness indicator of the generalized estimate for AL_j proposal is proposed to define as a pair:

$$ROB_j = < 1/K \sum_{k=1}^{K} \left| PER_{jk}^{*OP} - PER_{jk}^{OP} \right|, 1/K \sum_{k=1}^{K} \left| PER_{jk}^{*P} - PER_{jk}^{P} \right| > \tag{24}$$

The estimates obtained of perspectivity and robustness are used at the stages of proposals assessment:

- To initiate the procedure of individual estimates deliberative agreement;
- As input data for this procedure and the procedure of unacceptable Proposals screening.

At the stage of final selecting the Decision option these estimates are used for both merely selecting and Decision adaptive capabilities analyzing.

4. Uncertainty Handling

Information uncertainty with various causes and forms concerning various elements of PD process for reference Decision forming (See (1)) is one of inspiring factors PD process to support. The most important information structures of this process for which elements definition incompleteness impacts the input data and performing modes of procedures at the process stages are as follows: Assessment context, Alternative Proposal Specification and argumentation and Operands of conditions pertinent to Perspectivity model.

Element's current information uncertainty is characterized with a pair

$$< UR, UF > \tag{25}$$

where UR is the cause of uncertainty, one of the following: 1 – available facts unawareness, 2 – processes operation volatility and dynamicity, 3 – stakeholders' viewpoints conflicts, 4 –the system of business interests and viewpoints instability; UF is an information presentation format, namely: 1 – information array with gaps, 2 – a set of options pertinent to various business groups, 3 – a set of meaning versions equally plausible at the forming time; 4 – element representation with some conceptual components being omitted; 5 – meaning interval localization.

The modes of data with information uncertainty represented by means of a given format and localized within the above-mentioned information structures operating within three basic procedures of PD process are characterized with Table 3.

Information about each information element used for reference Decision elaborating is proposed to represent by means of the Uncertainty Map $UCARD,$ as an essential component of PD Process results. Within $UCARD,$ an information element EL is characterized with a structured tuple:

Table 3

Table 3 – Modes of uncertainty handling in PD process

Procedure	Information structure	Information presentation format	Operation mode
Alternative Proposals individual assessment	Alternative Proposal specification	UF_1	Expert's use of meanings pertinent to his viewpoint
		UF_3, UF_5	Identifying the most and the least appropriate values
		UF_1, UF_4	Assessing only those Perspectivity model elements not requiring knowledge about unknown properties
Idem	Assessment context	UF_1 (ISM elements, other stages results)	Assessing only leaves subset in Perspectivity model being provided with information
		UF_4 (previous stages results)	Hypothetical providing of the best and the worst meanings based on analogues and best practices
Idem	Idem	UF_3, UF_5	Identifying the most and the least appropriate values
Deliberative agreement of estimates	Context: elements used for argumentation	$UF_1 - UF_5$	Analysis of the estimates inconsistency causes and sources Elaborating mutually acceptable variant of estimate with its summing argumentation
Idem	Alternative Proposal specification	UF_2, UF_4, UF_5	Identifying critical inconsistencies of alternatives interpretation Elaborating the common view on the range of possible meanings of properties Eliminating alternatives not assuming a compromise interpretation from further consideration Identifying incompatible viewpoints for next iteration with additional data
Robustness Assessment	Operands of conditions	$UF_1 - UF_5$	Using the best and the worst meanings of the elements with information uncertainty obtained during assessment and deliberative agreement procedures

$$UCH(El) = \{< Et_i, UF, UR, \{< Z_K^{OPT}(EL), Z_K^{PES}(EL) >\}_{K=1}^{K}, < Z_G^{OPT}(EL), Z_G^{PES}(EL) >, N_1, N_2, N_3, N_4 \}_{i=1}^{I} \quad (26)$$

where Et_i is the stage where the information is used in procedures; UF, UR correspond (24); Z_K^{OPT}, Z_K^{PES} are the most and the least appropriate EL's meanings accepted by k-th Expert; Z_G^{OPT}, Z_G^{PES} are the corresponding meanings being formed by deliberative procedures; N_1 is the relative frequency of using EL by Experts; N_2 is the proportion of model $MPERS$ leaves being assessed with EL;

N_3, N_4 are respectively the proportions of C and CF conditions from $MPERS$ (See (18)), for which EL is actual.

Uncertainty map is used during Analytical Review of reference Decision engineering for its further operational use. Recommendations within Analytical Review addresses:

- Conditions of PD process results direct using and the list of their suitable constituents;
- Results' elements requiring adaptation as well as operations necessary for it;
- Knowledge components represented with the elements of reference Decision, suitable for reuse over DMDU processes with MPD model (1).

5. Adaptive Reference Decision Elaborating

Previous sections specify PD Process of forming an adaptive Decision within DMDU EAM methodology as:

- The sequence of stages and their execution information environment (see (1), (2));
- The set of informational and procedural elements with prescribed types as constituents of the Process stage (see (11));
- The way of Expert knowledge organizing used for the analysis of Proposals perspectivity property and this property Robustness under the conditions of available information uncertainty of various forms.

This section provides a high-level and integrated description of activities sequence over this Process based on aspects considered with previous sections and further detailizes some stages and procedures.

The sequence of PD Process stages is linear, but allowes for iterative cycles within the stages.

The First Stage.

Deliberative procedure of the Problem Statement provided analysis with clarifying and accepting the Crisis situation Model. Formal definition the class Decision is pertinent to and searching for analogues being explored. Deliberative procedure of Decision frame description and Information Uncertainty Map for the information elements accepted.

The Second Stage.

Proposals creating related to the goal of the Crisis situation impacting (direct or indirect) with identifying the impact's object and its current state. Proposal's argumentation forming in terms of used ontological relationships and precedents as well as relevant professional and domain experience.

The Third Stage.

Reference Perspectivity model updating for the impacting goal. Revising sub-goals considered in reference Perspectivity model. Eliciting additional conditions for given sub-nodes of the hierarchy nodes sufficiency properties violation. Update the set of external threats to sub-goals represented with the hierarchy nodes. Supplement the Sates of the Art being assessed directly and recommended assessment context.

Individual and group procedures of critical system thinking [9] are used for the activities above as well as deliberative procedure of Perspectivity model Harmonized version forming.

Providing optimistic and pessimistic meanings of information context undefined elements.

Procedure performing of certainty factor extreme values individual expert assessment for the States of the Art corresponding the leaves of Perspectivity model Harmonized version. Identifying the individual assessment contexts and their elements meanings: optimistic and pessimistic.

Individual assessment of coefficients of certainty. Information Uncertainty Map updating.

Integrating estimates formally up to the States of the Art hierarchy. Obtaining the pair of individual estimates for Proposal AL_j $< PER_{jk}^{OP}, PER_{jk}^{P} >$.

Calculation the pair of estimates $< PER_{jk}^{*OP}, PER_{jk}^{*P} >$ formally considering all the limitations and conditions from the Harmonized version of Perspectivity model.

Formal analysis of individual perspectivity estimates and their generalization with respect to Experts list: screening unacceptable Proposals and obtaining estimate's pair $< PER_{j}^{OP}, PER_{j}^{P} >$ for those Proposals that are recognized as acceptable. Formal calculation the Perspectivity's robustness estimate for accepted Proposals.

Adjusting generalized integrated results by the members of expert group. Approval these or passing to the participatory procedure of adjusting.

Participatory procedure of the Perspectivity and Robustness estimates adjusting through Delphi process with expert estimates and their arguments in a tour [13] and also providing the Experts with the results of previous procedures at this stage. Optional iteration the stage procedures being performed unsatisfactorily using the information expertly updated.

The activities above benefit in concordant estimates obtaining, alternative Proposals eliminated from consideration identifying, optional interrupting the Process to obtain additional information.

The stage results are as follows: the set of acceptable Proposals regarding the goal of impacting the Crisis situation; pessimistic and optimistic estimates of these Proposals Perspectivity and Robustness with their informational arguments; updated Information Uncertainty Map.

The Fourth Stage.

Proposals creating related to the measure the goal of impacting the Crisis situation to support.

The Proposal is formed as a quintuple

$$PRA_{ij} =< G_i , A_{ij} , R_{ij} , S_{ij} , Arg_{ij} >$$

where G_i is one of those impacting goals being recognized as acceptable at the Stage 3; A_{ij} is the j-th kind of measures (actions); R_{ij} is the description of necessary resources; S_{ij} denotes performing subjects; Arg_{ij} is the Proposal argumentation.

This argumentation provides success precedents for similar target objects, characteristics of possible side effects and their consequences, resources availability under current Decision frame etc.

If the measure parameters are set with information uncertainty the Information Uncertainty Map is respectively updated.

The Results are represented with the Proposal array $\{\{PRA_{ij}\}_{i=1}^{N}\}_{j=1}^{M_i}$, where N is the number of Proposals related to the impact goal being considered; M_i is the number of Proposals concerning the impact measure provided for G_i.

The Fifth Stage.

The sequence of actions being performed at the stage is in whole identical to Stage 3. The difference is just handling with the reference Perspectivity model for the impacting measures. Besides that Proposal related to the impacting goal G_i for which all M_i proposals related to the measure proved to be unacceptable is removed from the list of acceptable ones.

The Stage results are as follows:

$$\{\{< PER_{ij}^{OP} , PER_{ij}^{P} >, < PER_{ij}^{*OP} , PER_{ij}^{*P} >, < ROB_{ij}^{OP} , ROB_{ij}^{P} >\}_{i=1}^{N}\}_{j=1}^{M_i} \qquad (27)$$

The Sixth Stage.

At the stage the following tasks are solved:

- Final selecting the goal of the Crisis situation impacting and the means to achieve it – in accordance with the current priorities and expectations system;
- Preparing options that are the most acceptable under alternative situation evolving;
- Providing analytical rational for further adaptive usage of the Process results;
- Saving the results for reuse over the further coping of similar Crisis situations.

The procedure of optimal final selecting uses one of the target function prescribed forms where the operands are the set (27) elements depending on the Experts answers provided to the check list questions regarding the essence and weight of their preferences related to such the oppositions: goal effectiveness/way of goal achieving effectiveness; Perspectivity/Robustness; benefit maximization/ risk minimization; effectiveness under external threats absence/resilience to threats.

The results of optimization being performed using all the target functions (selected based on each preferences collection being provided) are submitted to expert group for deliberative adjusting the final result, namely the «Goal – Way» pair.

Decision Analytical review that is also pertinent to the stage results is created by means of the formal procedure using the data from the Information Uncertainty Map.

Analytical review includes:

- Effectiveness estimate of uncertainty presenting formats and operating modes being used over PD process (from the perspective of changes being adopted in new iterations and the level of using by Experts the information provided);
- Level of definability losses estimate being caused with the information uncertainty of a certain Process element assessment for the Perspectivity estimates;
- Recommendations for using these analytical data to determine: the conditions of the reference results direct usage, the suitability of certain operations to adapt the reference results, the appropriate corrections of the process elements for reuse when making similar Decisions.

Thus PD Process creates knowledge about the Decision and handles it through harmonized application of formal procedures, individual expert assessment procedures and procedures for deliberative engineering the process model elements.

Creating the common information space ensures equal information awareness of participants, unified format for expert judgments and their argumentation providing as well as storing and possible re-use of all the knowledge obtained during the Process execution.

For subsequent reference results obtained adapting over immediate preparing for their operational use the analytical Recommendations are purposed that enable the Process elements to be revised determining and adaptation performing subject to the information changes made.

6. Conclusion and Future work

The ultimate goal of DMDU EAM methodology elaboration is engineering the tools to support its formal mechanisms and human-machine procedures information and technological environment that will allow for DMDU EAM tailoring for the specific OMS domain and management relationships.

Necessary functional components of appropriate support tools include foremost:

- Software packages (SP) to administer individual and group expertises using the Perspectivity and Robustness models and enabling typified argumentation analysis;
- Ontological support tools to maintain and align the processes of strategic and anticipatory anti-crisis OMS decisions reference making and adapting;
- Tools to administer the common information environment;
- Components to support multi-stage and iterative Decision life cycle process;
- Techniques to organize and perform human-machine procedures;
- Tools to visualize the processes operation and OMS Decisions system current state.

Preliminary corresponding work being focused on defense resource management domain is now performing in the Institute of Software Systems of the National Academy of Sciences (SSI of NAS) of Ukraine.

It concerns further development of SP "Diagnostic expertise" [14] that supports handling the expert evaluation hierarchical multi-criteria model and uses production rules to diagnose the state of explored object with recommendations providing about suitable further actions with it based on a comprehensive analysis of individual and aggregated criteria estimates.

The authors' rational for complex coordination of logistic Decisions system within the Armed Forces of Ukraine is characterized in [15].

The special efforts are currently purposed at including NATO basic logistics software LOGFAS into the expert-analytical decision-making processes [16]. Corresponding work was launched during LOGFAS national extension engineering in SSI of NAS of Ukraine.

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