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ORIGINAL ARTICLE

THREE-FACTOR UTILITY FUNCTION - THE SAFETY OF PILOTS LEVERING INSTRUMENT

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Introduction: The aim of the research was to find the limits of applicability of a "two-factor utility function" by introduction of a three-factor utility function.

Methods: The proposed three-factor utility function allows the comprehensive analysis of the streams of interrelations, interactions of the individual ("psychosomatic") layers of the system, the state of behaviour ("health") of a generalized agent (system), the state of nature and the state of challenges and threats coming from the environment that is understood holistically as a whole.

Results: Behaviour of the three-factor utility function in solving decision problems complex dynamic systems was examined, and the results obtained by means of computer simulation methods from L number of experiments proved its effectiveness.

Conclusions: The three-factor utility function leads to effective solutions to the complex system, information and decision-making problems, as well as effective solutions in management and controlling, and the function itself constitutes a significant development of existing scientific achievements in the field of information technology and is of great practical importance.

Keywords: cognitive functions, ontology, modeling, dynamic processes simulations, decision making, computer aided trainings, systems integration, synergy effect

Figures: 8 • **References:** 9 • **Full-text PDF:** http://www.pjamp.com • **Copyright** © 2013 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

The aim of the research presented herein was to find the limits of applicability of a well-known and a very attractive so-called "two-factor utility function", proposed by R. Kulikowski (1998); the limits, which occur in solving the complex decision-making problems in the *multi-agent IT and controlling systems* in the complex, *dynamic environments* with extreme conditions.

It has already become a truism that practically every human action is a kind of a game[1] associated with the process of the exchange of definite "values" for other values that are specific to a particular game. This is about a generalized *notion of a value*. The process of the exchange is concurrently accompanied by the adequate decision-making process.

We have selected two well-known definitions out of many definitions of a human decision; one of them relates to the selection of the course of action, and the second one concerns the choice of the method of action, and on the basis of them we have created a certain composition that is consistent with the recognized system of values and corresponding to the adopted model of phased decision-making.

Consequently, the essence of the conclusive decision is defined as follows:

"The essence of the conclusive decision made on the basis of the sequence of preliminary decisions after each stage of decision-making process, is the fulfilment of a given "stop" rule (see [2]) based on the so-called *rationalism of the three-factor utility function* by A. Janicki" [3,4].

A certain class of dynamic systems, operating in the extreme environmental conditions, and treated as some "beings" of the upper level of abstraction in terms of the ontology[2] was a reality spur that stimulated formulation of a research problem.

METHODS

Formulation of research problem

It is a well-known fact (see [6,7,8]) that any decision in human actions is dependent on factors such as *so-called drives*, i.e. entrepreneurial actions and *so-called defences*, i.e. protective and defensive (precautionary) actions. These two motivations of the decision-maker were reflected in the two-factor utility function proposed by R. Kulikowski. In that author's opinion, increasing complexity of events and processes occurring in the reality that surrounds us, often in conditions of a growing chaos, enforces decisions consisting in the choice of the best variant of the action out of the set of all development opportunities. It would be necessary to determine the *decision-maker's utility function* in an analytical way so that such decisions could be based on a strict optimisation methodology.

This problem is not easily solvable, since, in fact, the form of the above-mentioned function depends on the *decision-makers' subjective attitudes.* Constructive approach to solving such a problem consists in calculation of the optimal solutions maximizing the objective function, which is the utility function. The key task here is to develop normative models that will motivate decision-makers to assume such models to be corresponding to the real objectives and motivations.

At present, the basic development challenge is to create the information society and to develop the knowledge-based economy. The essential challenge is also to refine the normative models for support of development decisions, taking into consideration various forms of risk.

The developed theory of the two-factor utility function along with the methodology based thereon is used in solving numerous practical problems. Nevertheless, our research revealed the boundaries of effectiveness of the aforesaid methodology when applied to the problems inherent in such a class of the comprehensive systems as those stated below.

General assumptions of research problem – description of a being

People such as operators and decision-makers in the transdisciplinary diagnostic, therapeutic, monitoring, controlling and executive complexes, who fulfil their tasks facing a threat and being under pressure, are inevitably objects of special scientific interest and treatment.

Their preparation, training and maintaining a high quality of functioning take time and involve huge financial resources, and the factor of responsibility increases with applying more and more expensive and unique devices on living organisms under conditions of stress.

A significant cognitive problem of critical importance for the practice is the state of ecology of each of such individuals, which is understood in contemporary terms on the basis of Wolanski's

1 Fundamentals of such an approach are based, among others, on the achievements of von Neumann and Morgenstern, Savage, Tversky, and Kahneman.

2 The phase of conceptualization including: a hierarchy of the abstraction levels and anthology; theories; actions; implementations; equipping with machinery (equipment, connections, allocation of resources).

theory [9], and in particular the measurability of such a state. More specifically, it is about the measurability of interactions (interdependencies and mutual interactions) between the human and the nature, as well as between the human and the social systems, aimed at stabilization (homeostasis) of the system as a whole.

The holistic determination of the assessment measures of the state of human being ecology (in case of the person such as a decision-maker in extreme environments), of his/her objective function and of the quality assessment of solutions used by him/her, conditions the possibility to use the extensive methodology of systems theory, methodology of system research and advanced computing platforms that model, optimize and support the complex decision-making processes under the conditions of uncertainty.

Measurability of the state of human being ecology in case of each of the actors at the theatre of actions in terms of the game-theory models of situations currently attracts the attention of both theorists and practitioners of advanced information and decision-making systems. This concerns in particular the systems, which are essential to public life, including financial, military, police systems, as well as protection and rescue systems in a broad sense.

The three-factor utility function developed by the author, constituting a holistic measure of purposefulness and/or usefulness of the system interpreted as an agency created out of intelligent agents (see [8]), allows for a comprehensive analysis of streams of connections and mutual psychosomatic interactions among the health condition of a generalized agent, the state of nature and the state of challenges and threats of the environment as a whole.

The definition of this three-factor utility function allows to interpret personal behaviours as composed of the will to succeed, the fear of threats (dread, precautionary measures) and the internal coherence of a given individual in terms of Antonovsky's theory (see [1]).

Therefore, it is about building a developed methodology along with tools created on the basis of preliminary empirical research (modelling and computer simulations) on the exemplary system with multi-purpose decision-makers acting under the extreme stress-inducing conditions, which constitutes a specific being.

For this purpose we distinguish the category of "behavioural decision theories" and the category of "mathematical decision theories." Two situations of high complexity of the problems and a high level of uncertainty therein have been distinguished within the universe of the discourse, and they are as follows:

1. A situation, in which a person (a decision-maker), who takes decisions directly and on their own, has to act instinctively to a significant extent.
2. A situation, in which a person (a decision-maker) takes the conclusive decision, supporting himself/herself by means of gradual preliminary decisions prepared by the decision-making team (a group of people or an appropriate expert system).

Models of the processes occurring in both situations are of a game-theory nature with strong timing conditions as well as blurs of data and values.

RESULTS

Solution to research problem

A solution to the problem raised above was based on the results of the said two-factor utility function by R. Kulikowski, which in a mathematical form presents the fact (well-known in behavioural psychoanalysis) that actions and decisions taken by a human are the result of two factors. The first factor corresponds to the force pushing the human to take risk-related actions, and was previously called the "drives" factor.

The second factor, called previously the "defences" factor, is associated with all the prerequisites, which inhibit the human from risking and induce him/her to remain in the state of relative safety. Therefore, in a generalized form, this function is defined by the following formula:

$$U(x)=F\,[X,Y].$$

Due to the requirement of homogeneity of a given utility function, R. Kulikowski gave it the form of the Cobb-Douglas function[3]

$$U(x) = X^{\beta}Y^{1-\beta}\ ; \quad \beta \in [0,1],$$

where X represents a factor related to the expected benefits (in the form of any resources) of taking the considered decision; Y is a factor related to the risk of loss of the resources involved in the implementation of the considered project, while β is a factor defining the level of determination to act.

3 Cobb-Douglas function effectively reflects the dependence of the value of production in a broad sense on the inputs for factors of production (labour and capital resources) e.g. value of solving the problem (calculations).

It is easy to notice that the decision-maker with greater determination to act will be prone to attaching less significance to risk of action, whereas the decision-maker, who chooses the more precautionary strategy, will give more importance to the risk of the project than to the possible benefits resulting from the action taken.

Although solving a specific class of problems by applying the two-factor utility function is more efficient than by applying the classical methods, in case of the problems of the highest level of complexity and indeterminacy it was necessary to create the method, which would accurately reflect the essence of the matter, and the appropriate tools in order to solve them.

The three-factor utility function proposed by the author constitutes a holistic measure of purposefulness and/or usefulness of the system, interpreted as the agency created out of the intelligent agents meaning that [8] it allows for the comprehensive analysis of the streams of interrelations, interactions of the individual ("psychosomatic") layers of the system, the state of behaviour ("health") of a generalized agent (system), the state of nature and the state of challenges and threats coming from the environment that is understood holistically as a whole.

The introduced definition of the three-factor utility function allows for the interpretation of the individual decision-makers' (intelligent agents') behaviours, as composed of the will to succeed, the fear of threats and the internal coherence of a given system (agency) as defined in Minsky's theory.

As a result of research on the quality of solutions to a given problem by applying the model of function by R. Kulikowski and the methodology appropriate for the branch of mathematics called experimental mathematics, the author has built a model of a three-factor function in the following form:

$$U(x) = [X^{\beta} Y^{1-\beta}]^{\alpha} V^{1-\alpha} \;; \quad \alpha \in [0,1] \;; \quad \beta \in [0,1],$$

where the factor V represents the so called *survival coefficient*; the function as a whole presents decision-making processes in the natural environment.

The decision-maker, who is subject to continuous stress, needs to survive in such an environment and take actions maximizing his/her profits. Antonovsky made the way of coping with stress, i.e. surviving in an unfavourable environment, conditional on the sense of coherence. Successful survival depends on the knowledge of the surrounding environment and the ability to adapt thereto, i.e. the ability to act within it in a way that steadily brings benefits.

Successful survival is the resultant of three specific interactions (vectors); namely:

– Understanding the environment. The condition is to adequately understand the environment and the mechanisms that govern it to the extent that will allow to learn in depth about the essence of the stimuli which affect us and to foresee the consequences of the decisions taken. This factor is denoted by **Z** - as a measure of understanding of the competitive (game-theory) environment.
– Feasibility assessment. The decision-maker, while setting about acting, has to properly assess the resources he/she has as well as to assess what resources he/she needs in order to complete the project. This factor is denoted by **W** - as a measure of the availability of resources.
– Reasonableness of action. Person taking decisions must have a sense of reasonableness of action, in which he/she wants to get involved. This factor is denoted by **S** - as a measure of readiness for effort, commitment and/or dedication to the cause (so-called entrepreneurial spirit).

Thus, the survival coefficient V is expressed by the product of the following vectors

$$V = Z \times W \times S$$

and it constitutes a measure of the ability to survive under the pressure of stressors.

The influence of survival coefficient on the utility function should be analysed, while determining the meaning this coefficient. With the increase of this coefficient the significance, which is attached by the decision-maker to that specific part of the utility function that is associated with the action, increases and the significance, associated with the survival coefficient, decreases. Therefore, this parameter may determine the decision-maker's approach, his/her willingness to act or to protect himself/herself.

The directions of the vectors in space depend on the decision-maker's state of the sense of coherence; the higher the state is, the smaller the angle between the **S** and **W** vectors is, the vectors are more "consistent" and their resultant is higher. It follows that the greater the sense of coherence is, the greater the value of the coefficient of survival is. This can be illustrated by means of a specific mechanism of space-time curvature by a given "mass", which causes the effect of "gravity". The sense of coherence depends on the personality (strength of will; resources), so its distinctive features, in this model, may be equated with a certain being that creates the said gravity. The personality may be shaped over time, thus, it may reveal some slow changes, and therefore, the decision-maker's sense of coherence may be variable. However, innate or trained stability of personality has a crucial meaning for the practice.

Quality assessment of solution

Drawing a diagram illustrating the influence of the state of coherence on the decision-making process[4] can be started with imagining a certain plane with three divergent vectors:

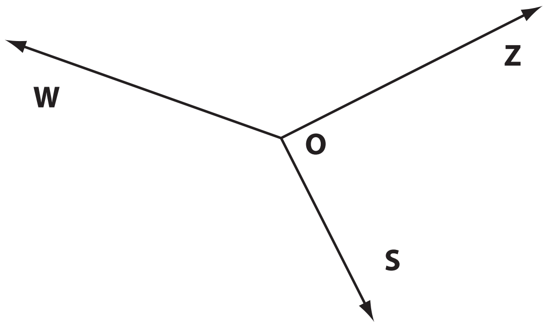

Fig. 1. Position of vectors on a given plane.
Source: own, DIST.

The resultant of these vectors will be close to zero, because they are divergent and inconsistent. Only applying a certain "force" to the O point of concentration of a certain "mass" will introduce a kind of "gravity", which will curve the space and bring directions of the vectors closer to each other. Then the resultant of these vectors will increase. The mass reflects the adequate resource of spirituality[5] of a given person (a decision-maker).

The conducted research gave the basis for proposing a thesis on existence of the analogy between the decision-maker's (agency's) internal coherence and the said "gravity". Therefore, the greater the sense of coherence is the more the vectors, representing the factors of utility function, aim at parallelism, maximizing the resultant.

The said "gravity" force is interpreted as a decision-maker's strength of will to make the final decision computable throughout the entire decision-making (controlling) process regardless of the impact of stress-inducing factors in a given situation and/or environment.

Behaviour of the three-factor utility function in solving decision problems – in such complex dynamic systems as modelling – was examined, and the results obtained by means of computer simulation methods from L number of experiments, are presented in the following figures.

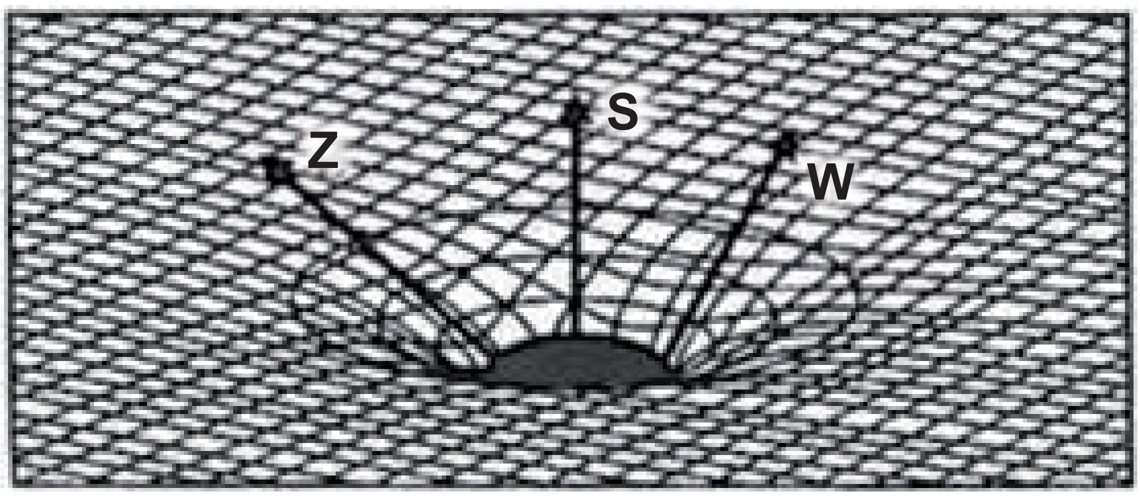

Fig. 2. "Gravitational" extension of coherence.
Source: own, DIST.

4 See: internal publication of Department of Information Society Technologies at the Faculty of Mathematics and Natural Sciences at the John Paul II Catholic University of Lublin.

5 See: definition of "spiritual" ("duchowy") e.g. in "Mały Słownik Języka Polskiego" ("Little Dictionary of the Polish Language") published by PWN, Warsaw 1968, p. 141.

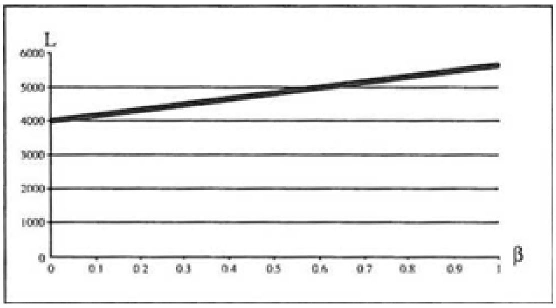

Fig. 3. Two-factor utility function.
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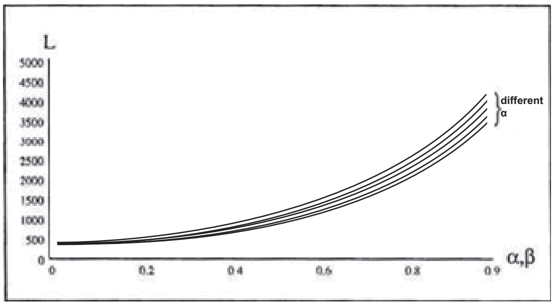

Fig. 4. Three-factor utility function.
Source: own, DIST.

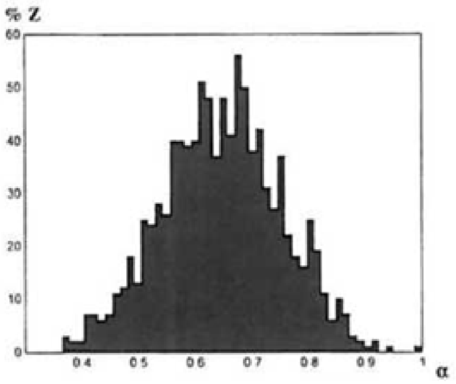

Fig. 5. Distribution of probability of understanding the environment.
Source: own, DIST.

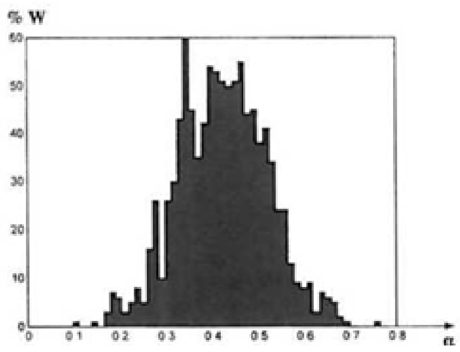

Fig. 6. Distribution of probability of feasibility assessment.
Source: own, DIST.

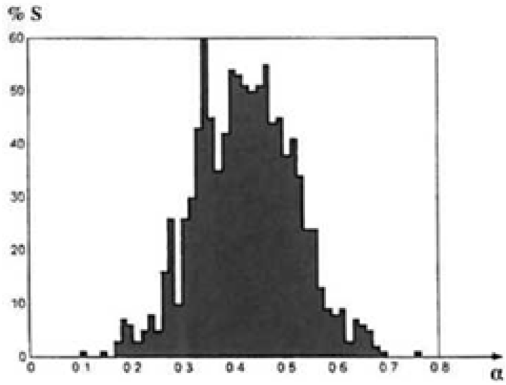

Fig. 7. Distribution of probability of reasonableness of action.
Source: own, DIST.

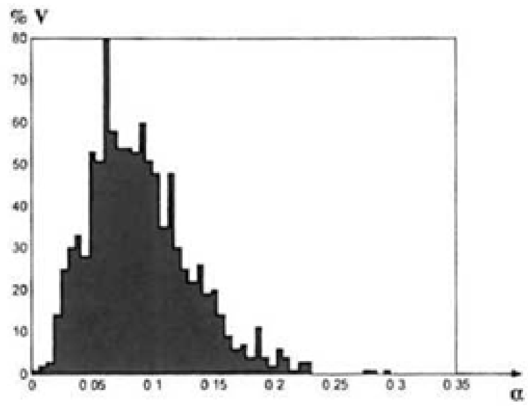

Fig. 8. Distribution of probability of ability to survive (see. Erlang distribution)
Source: own, DIST.

There is a correlation, which may be determined experimentally, between the given person's (agency's) ability to survive and each of his/her mental interactions (vectors).

Our computable results are significantly close to A. Antonovsky's empirical results.

CONCLUSION

It must be concluded, as it has been experimentally demonstrated, that the methodology of using the three-factor utility function leads to effective solutions to the complex system, information and decision-making problems, as well as effective solutions in management and controlling, and the function itself constitutes a significant development of existing scientific achievements in the field of information technology and is of great practical importance. Thus, the field of research and applications of the multi-factor utility functions in the NP-hard optimization problems and in solving satisfaction problem has been expanded.

Recommendations

The paper addressed to the interested readers presents an essential part of the achievements in the work of building and developing of the newly created Research and Educational Laboratory. Due to the unique idea of integration of the various IT techniques and the synergy effect obtained as a result of it, the original e-platform for modelling and simulations has been built, which was named briefly LabTSI™ by us. The applied solutions meet well the needs of both research workers and students in the scope of research on information society technologies, their practical applications, especially in the field of modelling and simulations of decision-making processes, as well as solving specific problems of the knowledge-based economy and social issues related to the said problems.

LabTSI™ serves well for conducting research in the already recognized areas of e-health, e-business, e-participation, e-learning and cybersecurity [5]. The distributed structure of the platform allows also to do research on issues of parallelism of computations, on the concurrency of algorithms and processes, as well as on the related interdisciplinary issues.

The ability to control computing power of LabTSI™ and the integration with the external structures of supercomputers create practically unlimited possibilities for the user in terms of solving the modelling and optimization of the selected problems.

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