Virtual Team Tasks Performance Evaluation Based on Multi-level Fuzzy Comprehensive Method

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Abstract **— The article analyses the research problem, what model for performance evaluation of virtual team could effectively serve a project leader by applying intelligent computational methods, which could reflect human cogitation. The hierarchical fuzzy comprehensive method of virtual team performance evaluation is suggested. The list of criteria of three groups (team, task and interaction) is elaborated for evaluation of project status and computed as the multi-level fuzzy vector. Expert evaluation, Shannon entropy and multi-level matrix computational methods are applied for experimental research of the model. The experimental results of comprehensive task evaluation by combining expert judgments and quantitative values derived from communication data are highly compatible and can assist project leader by providing valuable insights of underlying reasons affecting project outcome.**

Keywords - virtual team; task performance evaluation; human interaction management; multi-level fuzzy; comprehensive method.

I. INTRODUCTION

Globalization and penetration of information technologies are urging the need for new strategies of organizing projects in virtual mode and elaborating methods for their evaluation. Comparing to traditional attitudes the concept and principles of virtual work management are different not only due to the modes of communication in virtual and regular workspaces. Even experienced specialists and project leaders notify of numerous unexpected risks and difficulties, which undermine team efforts while working in virtual space. Recently, we can observe quite intensive informal discussions among project managers and leaders trying to reveal what brings the most significant influence in their efforts to streamline project progress, and what types of performance evaluation techniques could improve exposure of the real situation. This problem is important to project managers who apply both traditional and specific project methodologies. The group of team management problems in virtual environment is identified as e-leadership [1,2].

The traditional project management methodologies acknowledge administration and operational control. These techniques are characteristic for organizing work processes in the face-to-face environment, where prevailing methods of evaluation of progress status by the top-level organizational bodies are based on subjective insights. High level of subjective judgments and uncertainty makes project evaluation costly, time consuming and not all the time effective.

The process-based method Project Management Body of Knowledge (PMBOK) [3] accentuates the interaction-oriented tools and techniques for project team management: *Observation and Conversation, Project Performance Appraisals, Conflict Management, and Issue Log*.

Emerging project management approaches (such as Agile methodologies) emphasize importance of leadership in management process. Leader is assumed as the person who keeps the spotlight on the project vision, who inspires the team, who promotes teamwork and collaboration, who champions the project and removes obstacles hindering progress [4]. One of the most highly evaluated qualities of team leader is the ability to identify teamwork situation and project progress status. The effective tools and models for evaluation of the teamwork characteristics could enhance impact of personal qualities and to apply proper leadership techniques.

Human interaction management theory (HIM) presents different perspective of human work modeling principles and suggests specific notation for revealing interaction processes and their content among team members [5].

The interaction analysis oriented methods emphasize communication processes among team member, but do not provide evaluation tools, except plain statistics of communication intensity.

The issues of performance evaluation of the virtual teamwork are summarized in [6], where the possibility to derive interaction statistics-based variables and to find their causal relationships for evaluating project performance is explored by applying balanced scorecard approach. The intelligent analysis of virtual communication variables by combining neural networks and sensitivity analysis in [7] reveals that the information captured in project environment cannot be directly applied for evaluation of project members, but the combined neural network-based analysis of the derived variables can predict project outcomes with sufficient precision, while the impact of various variables is different. The feasibility of introduction of interaction–based variables and fuzzy rules of their interrelationships for comprehensive evaluation of project team performance is researched in [8].

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The article analyses the research problem, what model for analysis of virtual team could serve as effective evaluation tool for project leader, and to provide insights of performance by applying intelligent methods, which could reflect human cogitation.

In Section 2, we present analysis of pilot survey, which explores attitudes of experienced project managers towards performance evaluation. The survey outcomes enabled to suggest new method of creating hierarchical structure of criteria for performance evaluation of virtual project. As the experts denoted it is crucial to evaluate virtual team performance based on members' interaction analysis with the help of a system of interrelated criteria. In Section 3, we explain the structure and computational procedures of the model, designed by applying multi-level fuzzy comprehensive method, and aimed to identify and calibrate weights of task evaluation criteria. The conclusion and future works section summarizes the outcomes of the research and evaluation of adequateness of the model to the findings of pilot survey.

II. IDENTIFICATION OF PERFORMANCE EVALUATION CRITERIA

The research of criteria for evaluating performance of virtual team was made in two phases: the survey of project experts and computational analysis by applying method of multilevel fuzzy assessment.

In order to find out different attitudes and reveal significant insights to project performance evaluation fifteen project managers from different information technologies-related companies, participated in the interviewing process. The participants of the discussion were project managers of highest experience and technical consultants of JIRA Agile and JIRA Confluent solutions. They had experience of using ComindWork [9] and other applications of similar functionality for supervising virtual teams. The virtual collaboration environment ComindWork allows tracing various types of interactions among the members of project teams: messages, submitted files, timing settings and assignment of task status during project cycles [9].

The interviews consisted of two parts. The questions of the first part were formulated according to the main principles of Human Interaction management theory: Team building, Communication, Knowledge, Empowered time management, Collaborative, and Real time planning.

The second part of survey aimed to collect detailed information that could indicate difficulties of virtual project management and lack of e-leadership efficiency related to performance evaluation and situation assessment. One of the goals of the discussion was to find out which of the criteria could be derived and measured by using logging records of virtual collaboration interactions, such as ComindWork and further processed by the computational model.

After summarizing interviews the list of criteria for virtual team task performance evaluation based on human virtual interaction, was generated. After the reflective analytical discussion, the initial list of evaluation criteria was shortened. The refined version of the criteria list for human interaction evaluation is presented in Table 1. The criteria were grouped into three parts: *Team* evaluation criteria, *Task* evaluation criteria and *Interaction* evaluation criteria (Table 1). The *Team* and *Interaction* evaluation criteria were designed to evaluate performance either of teams or of individuals.

TABLE I. VIRTUAL TEAMWORK EVALUATION CRITERIA

Criteria and Description
Team evaluation criteria
Size- number of performers assigned to task during whole task implementation period (describes Team)
Variety - level of different roles assigned to task (describes Team)
Experience - level of team experience (describes Team and Individuals)
Characteristics - cumulative measures of personal characteristics: attitude to work/task implementation of the performer (describes Team and Individuals)
Hierarchy - level of team hierarchy (the rate of high, middle, junior experience within a particular role); (describes Team)
Task evaluation criteria
Phase - expert judgment /manager evaluation, parameter rate from a particular interval (beginning, middle or end of a particular project phase or iteration)
Task intelligence level - expert evaluation of human driven effort necessary to implement the task
Difficulty - expert evaluation of the level of task difficulty
Result clarity - expert / project team evaluation about the expected results and quality criteria
Organizational level - managers' evaluation of the strength of organizational structure of the team
Interaction evaluation criteria
Meeting level - expert evaluation (qualitative component) Information captured of system event logs (quantitative component, defining duration, number of topics, etc.) (describes Team)
Questioning level - number of questions sent to team members and requests for information to team leader and senior members (describes Team and Individuals)
Information sharing level - eagerness of team and individual members to share information (describes Team and Individuals)
Activity level - activeness level of the individual and team (describes Team and Individuals)
Punctuality level - punctuality level of the individual and team(describes Team and Individuals)
Maturity level - expert evaluation of the maturity level, which encompasses all characteristics (describes Team)

The second part of the research was executed together with project managers, virtual project environment application specialists and associated statistics research professionals. The goal of the second part was to develop or to adapt classical methods for creating computational measurement system for human interaction criteria. Everybody agreed that the most suitable criteria for *Team* evaluation were traditional articles of project management evaluation that have been deeply investigated by researchers and successfully adopted in practice by project managers. For deriving these criteria the liner mathematical calculations were suggested and applied.

The group of *Task evaluation* criteria was strongly based on expert knowledge and different task implementation circumstances that could not be accepted and analyzed as standard, as they were never known in advance. Therefore, all criteria in *Task* group were evaluated by expert judgment.

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The measurement of third group *Interaction evaluation* criteria was based on application of computational methods for processing data acquired by event recording in collaboration system by Interaction observing agents. For example, analysis of the parameter *Meeting level* accumulated information about the number of meetings, which were held during implementation of particular task, the duration of meetings, their types according to goal, planning time, number of participants and results. Parameters *Questioning level* and *Information sharing* level depend on number of messages and chats distribution according to their purpose types, also meetings held on a particular question (problem) or learning issues. *Activity* level summarized total amount of actions done by individuals and teams during task implementation period. *Punctuality level* referred to fact if interim or final results, reviews of tasks were fulfilled in time, whether the response to question was done with acceptable time delay, if there were no late arrangement of meetings. The last parameter *Maturity level* served as compound parameter, which accumulated all values from *Interaction* evaluation criteria group and two criteria of *Team* evaluation group (*Experience* and *Hierarchy*). The whole parameter set is presented in Table 2.

TABLE II. TEAM EVALUATION PARAMETERS

Input Criteria	*Team / Individual*	*Type*	*Measurement / Rate interval*
Team evaluation criteria			
Size (Rsz)	Team (T)	Quantitative	(Rsz) = ΣN(i) N-participant
Variety (Rvr)	Team (T)	Quantitative	(Rvr) = (ΣR(i)/N+ ΣR(n)/N)
Experience (Rex)	Individual (I) / Team (T)	Qualitative	(Rex) = (ΣR(i)L(i)/N+ ΣR(n)L(n)/N) R-role type L-experience level
Characteristics (Rch)	Individual (I)/Team (T)	Qualitative	Rate from interval [1…100]
Hierarchy (Rhr)	Team (T)		Rate from interval [1…10] (Rhr) = Σ(R(i)/L(i))
Task evaluation criteria			
Phase (Tph)	-	Qualitative	Rate from interval [1…n] accordingly to the project planning strategy
Task intelligent level (Tint)	-	Qualitative	Rate from an interval [-100…100];
Difficulty (Tdf)	-	Qualitative	Rate from an interval [0…100];
Result clarity (Trc)	-	Qualitative	Rate from an interval [0…50];
Organizational level (Iorg)	-	Qualitative	Rate from an interval [1…5];
Interaction evaluation criteria			
Meeting level (Ime)	Team	Quantitative / Compound	Rate from an interval [1...n];
Questioning level (Oque)	Individual / Team	Quantitative/ Compound	n- depends on task time duration and project team members;
Information sharing (Iish)	Individual / Team	Quantitative/ Compound	
Activity level (Iact)	Individual / Team	Quantitative/ Compound	
Punctuality level (Ipun)	Individual / Team	Quantitative/ Compound	
Maturity level (Ima)	Team	Statistical/ Compound	Rate from an interval [1…5]; (Ima) = f(Ime, Oque, Iish, Iact, Ipun)

The project management experts agreed that skillful observing team communication in virtual settings were no less significant and challenging as in the real environment.

The main information used by project leader to derive insights were team behavior patterns, interpretation of situations and task implementation processes by reviewing and evaluating content and intensity of team interactions. For example, analysis of team members' qualification and activities, questioning level, tendency to obey or to avoid obligations, punctuality in doing everything on time/not on time), keenness to share information and other characteristics could make it possible to identify the potential risk of task failure or possible delay. By employing insights from compound evaluation characteristics, the team leaders used to reduce risk of false judgment and make corrective actions of the situation concerning team behavior.

The presented model was further investigated by applying experimental data in order to compare the evaluation of team performance by skillful experts and by computational intelligence methods for defining values of the selected criteria.

Four possible situation outcomes of teamwork performance were chosen and experimentally tested by applying evaluation procedures of the suggested model:

(1) If task implementation is proceeding well;

(2) If the risk of task implementation delay can be identified;

(3) If the problem of non-understanding and chaos is accruing;

(4) If the project work is stagnated or omitted.

The computational method based on multilevel fuzzy approach for criteria estimation, the experimental setting, procedures of application the suggested model and evaluation of its results are discussed in the Section 3.

III. TASK PERFORMANCE EVALUATION MODEL BASED ON MULTI-LEVEL FUZZY METHOD

The method presents the new conceptual model of ability to integrate numerous criteria of different hierarchical levels for deriving status of the highest-level criteria. Multi-level Fuzzy Comprehensive method was chosen because of the variety of task evaluation criteria and their causal relationships. The quantitative evaluation by extracting information of virtual project environment is possible only for deriving part of the low-level criteria. The expert evaluation of the low-level criteria can be done with sufficient quality even by project leaders with lower experience, whereas expert judgment of high level criteria implies high risk and subjectivity. The method is based on Fuzzy analytic hierarchy process approach [10, 11], which allows formation of hierarchical criteria matrix, defining values of the low-level criteria and deriving values of the highest level criteria by calculating their weights and probabilities of status according to the defined status vector.

The experimental results are based on analysis of the performance of software solution implementation project team, which consisted of seven members. The database of interactions among team members in the virtual environment ComindWork consisted of 937 records, which were analyzed for evaluation of team performance.

The results of the expert evaluation for each level of criteria were benchmarked to the results obtained by applying the suggested model.

Task Performance evaluation of the Multi-level Fuzzy Comprehensive methods were applied by these steps:

(1) The determination of all level criteria sets;
(2) The identification of each criteria evaluation;
(3) The indication of weight for each criterion;
(4) The construction of single criteria evaluation matrix;
(5) The construction of comprehensive evaluation model.

A. The determination of all level criteria sets

Virtual team evaluation criteria are shown in Table 2. Variables differ by the following characteristics: category (applied for team, task or interaction), application type (applied for team or individual), measurement principles (qualitative, quantitative or compound) and measurement methods (Table 2). The set of criteria is arranged as the matrix C=(Cij), (i=1,2, … m), (j=1,2,…n), where (i) indicates higher level category and (j) category of lower hierarchical level.

B. The identification of each criteria evaluation

Evaluation of each criteria group is done according to the expert recommendations and specific results. The criteria evaluation set is constructed by applying status rating vector V = (V1, V2, V3, V4) = {Omit; Chaos; Delay; Well}.

C. Weight indication for the criteria

The weight values for each criterion were determined by two methods: they were defined by experts and by applying Shannon entropy measure [9].

The weight indicator corresponds to each criteria level W=(Wij), (i=1,2,..m), and (j=1,2,..n). The list of criteria and their weights are shown in Table 3, where (i) indicates first level criteria and (j) – the second level criteria. Weight parameters should meet several conditions: Wi, Wij >0, Wij < 1, and formula (1):

$$\sum_{i=1}^{m} Wi = \sum_{j=1}^{n} Wij = 1 \qquad (1)$$

In order to research if the quantitative measures of interaction can be computed and used to assist the project leader (and at least partially replace expert judgment), the Shannon entropy measure was applied [12]. Shannon entropy takes into account the information effectiveness of the analyzed data series and can be applied for defining weights of the criteria. We applied standard algorithm for calculating weights of interrelated criteria [10]. Our suggested list of criteria (Table 2) consisted both of expert judgment-based values and of quantitative measures, defined from human interaction statistics in virtual collaborative space.

TABLE III. LIST OF CRITERIA AND THEIR WEIGHTS

Category	*Weight*	*Criteria*	*Weight*
Team characteristics (C1)	0.2	(1) Team Size (C11)	0.15
		(2) Role variety (C12)	0.25
		(3) Experience (C13)	0.3
		(4) Characteristics (C14)	0.2
		(5) Team hierarchy level (C15)	0.1
Task characteristics (C2)	0.3	(6) Phase (C21)	0.1
		(7) Task intelligent level (C22)	0.2
		(8) Difficulty (C23)	0.1
		(9) Result clarity (C24)	0.2
		(10) Organizational level (C25)	0.4
Interaction characteristics (C3)	0.5	(11) Meeting level (C31)	0.1
		(12) Questioning level (C32)	0.15
		(13) Information sharing (C33)	0.15
		(14) Activity level (C34)	0.1
		(15) Punctuality level (C35)	0.2
		(16) Maturity level (C36)	0.3

We applied Shannon entropy for computing weights for the interaction-statistics-based criteria for the individual members and the project team (C13, C14, C32, C33, C34, and C35 from Table 3). We implied that the interaction data provided by the virtual collaborative space of the team can be applied for calculating part of the evaluation criteria set and provide insights for the project leader for further evaluation of the whole criteria set.

The results of weight assignment according to Shannon entropy measure, as presented in Table 4, are highly compatible to the weights set by experts (Table 3).

TABLE IV. WEIGHTS COMPUTED BY SHANNON ENTROPY METHOD

Criterion (C)		*Weight (W)*
C13	Rex	W1/0,273
C14	Rch	W2/0,121
C32	Oque	W3/0,237
C33	Iish	W4/0,106
C34	Iact	W5/0,130
C35	Ipun	W6/0,133

The differences in evaluation may have occurred because the experts put their weight values based on their long-term

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experience, and the Shannon's entropy method was applied to process the interaction data of a single project. The results encourage for further investigations aimed achieving validity of the experimental research.

Application of Multi-level Fuzzy Comprehensive method was intended to analyze experimental data in order to exploit hierarchical interrelationships of the criteria set and expert evaluations of the particular criteria in order to compute cumulative evaluation the team performance.

D. The construction of single criteria evaluation matrix

The single criteria evaluation matrix is constructed by using Matrix scheme for two or more indicators (2):

$$Rij = \begin{bmatrix} R_{i11} & R_{i12} & \dots & R_{i2v} \\ R_{i21} & R_{i22} & \dots & R_{i2v} \\ \dots & \dots & \dots & \dots \\ R_{in1} & R_{in2} & \dots & R_{inv} \end{bmatrix} \quad (2)$$

The evaluation matrix for the criteria set presented in Table 3 consists of expert grades. The following matrices R_{1j}, R_{2j}, R_{3j}, express expert judgment of probabilities of each situation outcome (3):

$$R_{1j} = \begin{bmatrix} 0,1 & 0,4 & 0,2 & 0,2 \\ 0,1 & 0,4 & 0,3 & 0,1 \\ 0,4 & 0,1 & 0,1 & 0,4 \\ 0,3 & 0,4 & 0,1 & 0,2 \\ 0,2 & 0,3 & 0,3 & 0,2 \end{bmatrix} R_{2j} = \begin{bmatrix} 0,1 & 0,3 & 0,3 & 0,3 \\ 0,3 & 0,1 & 0,3 & 0,3 \\ 0,1 & 0,4 & 0,4 & 0,1 \\ 0,1 & 0,4 & 0,3 & 0,2 \\ 0,5 & 0,2 & 0,1 & 0,2 \end{bmatrix}$$

$$R_{3j} = \begin{bmatrix} 0,2 & 0,3 & 0,2 & 0,2 \\ 0,4 & 0,3 & 0,2 & 0,1 \\ 0,2 & 0,2 & 0,3 & 0,3 \\ 0,2 & 0,3 & 0,3 & 0,2 \\ 0,2 & 0,1 & 0,4 & 0,3 \\ 0,1 & 0,3 & 0,4 & 0,2 \end{bmatrix} \quad (3)$$

E. The construction of Comprehensive evaluation

Comprehensive evaluation is multi-level process. The computation is performed starting with the lowest level criteria of the initial criteria set Ci = (Ci1, Ci2 … Cij), then processing to the highest level criteria C = (C1, C2, Cm). The comprehensive evaluation matrix for Ci is Bi, for C is B, as computed by (4) and (5):

$$B_i = W_i * R_v = (b_{i1}, b_{i2}, b_{i3}) \quad (4)$$

and

$$B = W * R = W * \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = (b_1, b_2, b_3) \quad (5)$$

The value vector V was applied for expert judgments. The computation results of the three criteria groups C1, C2 and C3 are evaluated according to values of vector V: (Omit; Chaos; Delay; Well) = {V1, V2, V3, V4}. The biggest element of the computed array means that the value of the computed criterion is equal to the corresponding element of the vector V with the highest probability. After applying the above-discussed computation procedures, the evaluation parameters for *Team*, *Task* and *Interaction* level characteristics (C1, C2, and C3) were computed and the project status evaluation was derived.

- *Team* characteristics:

$B1 = W1 * R1 = (0,24; 0,30; 0,19; 0,24)$

- *Task* characteristics:

$B2 = W2 * R2 = (0,3; 0,25; 0,23; 0,22)$

- *Interaction* characteristics:

$B3 = W3 * R3 = (0,2; 0,25; 0,34; 0,22)$

- *Comprehensive project task* evaluation:

$B = W * R = (0,24; 0,26; 0,28; 0,22)$.

The results lead to further interpretations and insights. The *Team* characteristic of the second level of Comprehensive evaluation was assigned value "Chaos" with the highest possibility (0,3). The *Task* characteristic was evaluated as "Omit" with the highest possibility (0,3). Analysis of *Interaction* denotes the situation of "Delay" (0,34). By accumulating all parameters according to multi-level fuzzy comprehensive evaluation method and calculating the compound situation, measure B the situation "Delay" could be identified with the highest probability (0,28).

Slightly different situation is identified in the case of applying calculation of criteria weights by Shannon entropy method, where the values of criteria subset are derived from interaction statistics information captured in the virtual project environment (Table 4). In this case the compound situation measure "Delay" has higher possibility equal to 0,29, as the B {*Omit; Chaos; Delay; Well*} = (0,24; 0,27; 0,29; 0,20).

The research results revealed that the suggested multi-level interaction system and expert judgment lead to similar results and can be applied to assist project leaders working in virtual environment. The human interaction instances registered during virtual teamwork can be used for deriving evaluation criteria and provide reliable insights for evaluating team performance and its outcomes. The initial results encourage that further research should be executed.

IV. CONCLUSION AND FUTURE WORK

The main drawback of applying existing methods (Agile, PMBOK, HIM) for project management in virtual environment is lack of measures for performance evaluation.

The analysis of virtual communication among project team members is mainly based on statistics of communication intensity, captured in the virtual project environment. The information of number of messages, submitted files and responses is not sufficient for providing in-depth insights for the project leader for comprehensive evaluation of task quality, individual input or risk of project outcomes.

The article presents solution for the research problem as the multi-level fuzzy comprehensive evaluation model for performance evaluation of virtual team. The variables and their multi-level structure were elaborated by applying method of expert survey. The performance of the model is based on measurement of the variables and assigning their weights indicating their impact for the project outcome. Sixteen criteria of three groups (team, task and interaction) were included to the model for evaluation of project status, computed as the multi-level fuzzy vector. The measurement of criteria is combined not only of expert evaluation but of quantitative values related to communication of project team members as well. Shannon entropy method is applied for processing communication-related information captured in virtual environment of project team.

The experimental research of consisting of pilot expert survey and analysis of project teamwork performance in virtual environment ComindWork allowed to positively evaluated the suggested model. The values of interaction statistics-based criteria processed by applying Shannon entropy were highly compatible to the values assigned by experts.

It allows concluding that at least part of criteria for project performance evaluation can be computed by processing information of virtual communication environment used by the project team. Project leaders can evaluate the other part of low-level qualitative criteria included to the hierarchical model. The highest level-criteria for evaluating situation and forecasting the project outcome involve the biggest risk and require mature experience of project leader.

The suggested method of multi-level fuzzy assessment allows applying computational model, to calculate the highest level-criteria and assist project leader by providing valuable insights of underlying reasons affecting these criteria.

The proposed multi-level fuzzy method is an innovative approach for project performance evaluation by creating hierarchical interrelationship structure of criteria and their measurement by combining expert evaluation and Shannon entropy. The suggested method based on fuzzy logic can provide better understanding to project outcomes considering ambiguous and imprecise data in a manner similar to the human thinking and the human judgment.

The validity of the model will be tested by future experimental research.

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