Monitoring, measurement and simulation of individual and teamwork performance in collaborative product development and design

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Abstract: ***Current management methods for intangible aspects of development projects are diversified across different research fields with lot of open questions. This paper presents a practical approach for monitoring, measuring and simulation of individual and teamwork performance within the collaborative engineering development and design projects.***

Keywords: ***individual and teamwork performance, actionable framework, work sampling, organizational meta-matrix, agent-based simulation***

1. Introduction

The execution of complex development project could be seen as a socio-technical conduct, "defined by history, context, individual values and wider structural frameworks" – actuality of the project [1]. However, an open question remains in a literature about how to deal with the aspects whose nature is intangible and non-financial. Measurement of intangible aspects intrigued many researchers, which provided and recommended various frameworks and methods related to the performance indicators for intangible elements in organizations. However, current measurement methods focusing on individuals' and teams' performance are scarce and scattered across different research fields. Extending project management indicators towards intangible aspects of collaborative development project could provide new insights and allow wider perspective on project execution [2], [3], [4], [5]. To supplement existing management tools, the objective of this paper is to propose a practical approach for monitoring, measuring and simulation of individual and teamwork performance within the collaborative engineering development projects.

2. Performance indicators for engineering systems development projects

Performance indicators are operative part of any performance measurement system, which provides information about the accomplishment of given objective. Takim and Akintoye [6] stated: "Performance indicators specify the measurable evidence necessary that a planned effort has achieved the desired result". As such, measuring performance can provide feedback about process or organization efficiency and effectiveness and increase odds of project and organization success [7], [8].

After analysis of project performance indicators implemented in different public and private organisations, Parmenter [9] concluded several facts about their nature and characteristics:

- Monetary measures are lagging indicators; therefore, non-monetary ones could provide more input-oriented perspective to the performance of the observed phenomenon.
- Frequent measurement can provide real-time information promptly.
- Appropriately formed performance indicators should indicate what type of action is necessary to improve the performance.
- Measures cannot just be used at the organizational level but also at lower levels (individuals and teams) to improve the management process in an operative way.
- Good performance indicators should influence more than just one aspect of the organization.

The performance indicators for intangible elements of collaborative engineering projects that can be found in the literature are usually abstract measures without proper description or metric. To enable measurement and monitoring of those aspects, there is a necessity to propose indicators that will focus on individual and team level and consequently provide socio-technical perspective [10]. In comparison with existing retrospective and lagging indicators, usage of leading indicators would provide a more accurate snapshot of the current situation and would enable monitoring of project performance from a different perspective.

The approach presented in the paper is built on state of the art principles for intellectual capital performance measurement for collaborative development projects in different sectors (such as aerospace, automotive, energy, transportation, and healthcare) [11]. Indicators extracted from the literature were subject to the screening process with an aim to select ones that are relevant for the development context. Identified indicators were classified into four categories that have been set as a focus of the approach:

- Competencies and knowledge development;
- Communication and information exchange;
- Innovativeness and ideation capability; and
- Motivation and satisfaction.

Refinement phase resulted in the candidate list of 140 performance indicators that was sent to industrial partners for validation (2 companies working on collaborative development projects in automotive and energy sectors). To each indicator, data gathering method was assigned to define measurement procedure and specify requirements for the implementation phase. As the outcome, the list of the 65 performance indicators for monitoring and measurement performance related to intangible aspects of individual and teamwork in collaborative engineering development projects was created.

After defining the performance indicator list, the analysis was continued in the direction of their mutual influence [11]. Literature that is dealing with this topic stated several benefits that could be gained from this type of analysis. First, based on the identified performance indicators' relations it is possible to reduce the number of indicators. Second, identification of relationships lays groundwork for the creation of cause-effect performance indicators diagrams that could then facilitate understanding of the indicators network [12].

The expert elicitation approach was selected as a method to build the performance indicators network. Based on literature review and understanding of the project management issues relevant to the individual and teamwork performance measurement, influence relationships between indicators were defined, and reasoning for them was provided. Representatives of industrial partners validated the resulting matrix. After the validation, community detection on indicators' network was performed to identify the performance indicators groups that are more densely connected internally in comparison to the rest of the network and to understand how the performance indicators for the different elements of intellectual capital on individual and team level are grouped together (Figure 1). Clusters of indicators related to the people domain, knowledge domain, resources domain and task domain were identified [11].

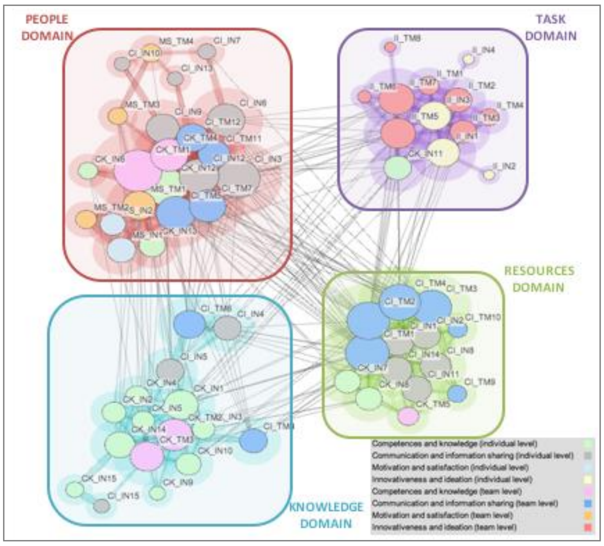

Figure 1. Community detection for performance indicators network

3. Performance indicators in action

To get the objective picture about individual and team performance in action, the creation of the performance indicator list and network was followed by building of the implementation framework (Figure 2). The developed framework consists of different gathering data approaches, data analysis methods, synthesis approaches for understanding the trends and organisational risks, and agent-based simulation of the collaborative teams performing development activities.

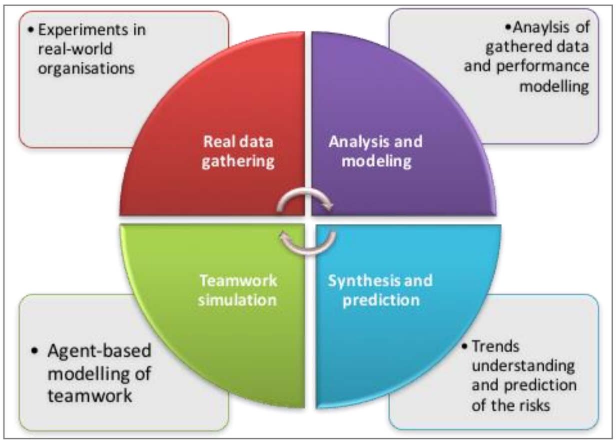

Figure 2. Framework for performance indicators in action

The framework was tested within two case studies. The first one was carried out in the SME whose research and development activities are focused on the systems for the generation, distribution, and transformation of electrical energy. The second case study was conducted in the large enterprise that is Tier 1 development and manufacturing supplier for the automotive industry in EU. In both studies, we selected team of 15 individuals whose main preoccupation was the collaborative development of the products and production systems.

3.1 Data gathering from real-world organisations

The three approaches were proposed and used for the data gathering: work sampling; surveys; and extraction from corporate IT systems.

Work sampling is a methodical work measurement method for estimation of time percentages participant spent on execution of activities [13]. The technique is based on data collection at certain time intervals as opposed to classical time studies. Statistical background of the work sampling can allow quantitative analysis of gathered data. As such, work sampling is the best choice to collect data for performance indicators whose value change with daily frequency. Within presented research, the work sampling application for mobile platforms was developed [14].

To obtain data for indicators on an individual level, which are related to competencies and knowledge of individual in a team, the 360-degree performance survey was selected. According to [15], even in 2002, 90% of Fortune 500 companies were using 360-degree or multi-rate performance review process. Within this method, the main idea is to set single individual as an evaluation object and to assess its performance encompassing different perspectives of its peers, superiors, and subordinates, but also embracing self-evaluation. Survey-based data gathering was also used in proposed framework related to the work environment and was carried out to get a more embracive picture of the teamwork context relevant for the study.

As the third approach for data gathering, corporate IT systems were proposed to be used as a source. Within this research, it could be applicable only to a few indicators since usually such captured data are often used for describing tangible and lagging aspects of project management.

3.2 Analysis of performance indicators dynamics

The analysis of collected data was divided into three parts:

1. Analysis of the aggregated data for the entire work sampling period for all team members
2. Analysis of the aggregated data for the entire sampling period for each individual team member
3. Analysis of daily dynamics of performance indicators for each team member and team as a whole

Analysis of the aggregated data for the entire data gathering period enables quantitative analysis of the context of the projects, work and activity types, nature of the information processing, manner of conducting the activities and personal motivation. Results obtained from the analysis of gathered data for the team as a whole and individually, allow a better perception of the distribution of different activity dimensions between team members and the way how various activities were conducted (example for one dimension is shown in Figure 3).

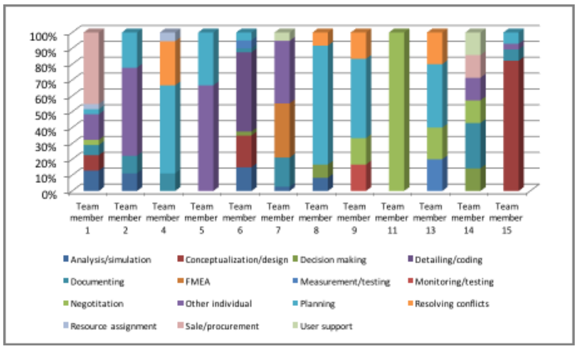

Figure 3. Percentage of time spent on particular development activities

In addition to the analysis of the aggregated data for the whole team and individuals, analysis of the gathered data was performed for each team member focusing on daily dynamics in order to understand the trends of the performance indicators as defined previously (example for the *Percentage of time spent on discussions* indicator is shown in Figure 4).

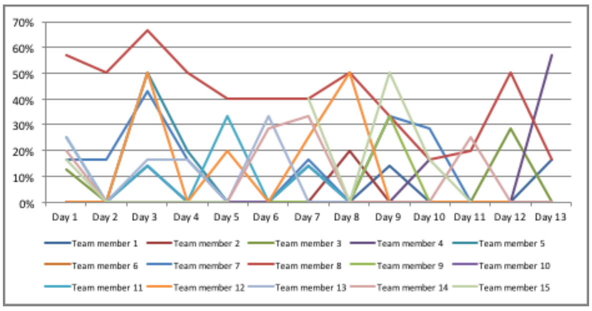

Figure 4. Change of values for *Percentage of time spent on discussions* indictor

The most commonly used approach for mapping data gathered by work sampling to performance indicators is to determine the ratio between the number of sampling points (the numerator) and the total number of sampling points (the denominator). Due to the high number of sampling points, the calculation becomes statistically relevant and enables quantification of individual performance indicators dynamics, which is otherwise difficult to define in quantified form. The values for the indicators determined by mapping data collected by the surveys was calculated as the average score.

3.3 Synthesis and risks prediction

As the third part of the framework, the synthesis of the organizational meta-matrix [16] was used for the identification of the organizational risks: critical team member risk, communication risk (interaction network is shown in Figure 5), resource allocation risk, redundancy risk, task risk, personal interaction risk, or performance risk.

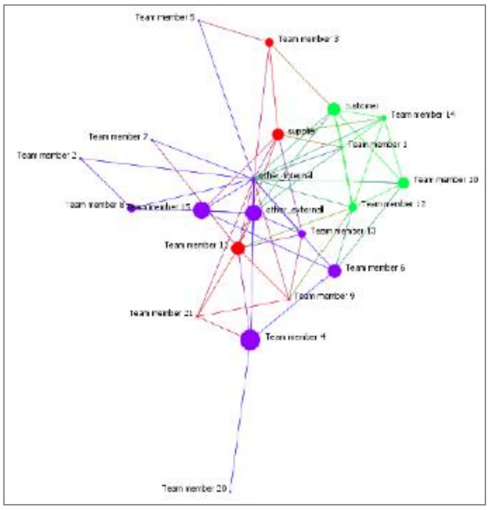

Figure 5. Team members' interaction network evolved during the observational period

The organizational risks are evolutionary and dynamic which implies that the synthesis should be based on longitudinal performance monitoring and measurement that captures the impact of indicator value changes over the time. Dynamic Network Analysis was applied since it incorporates network topology change and longitudinally quantifies the organizational structure elements dynamics and as such may be used for prediction of the organizational risks.

3.4 Agent-based simulation

Since longitudinal studies tend to be time and resource consuming (particular organizational context, a limited number of participants in data gathering, long-term effects), the simulation of the teamwork in collaborative development processes was added to the framework to be used for comparison of different team composition for various types of the development projects. The initial implementation includes extension of the model developed by Crowder et al. [17].

Modifications were focused on the helping-learning strategy of design agents and more comprehensive modelling of formal and informal team activities, based on the insights from the data gathering and analysis of the individual and team work performance indicators from the two case studies. The details of the simulation model and implementation are described in [18], while part of the model and outputs are illustrated in Figure 6.

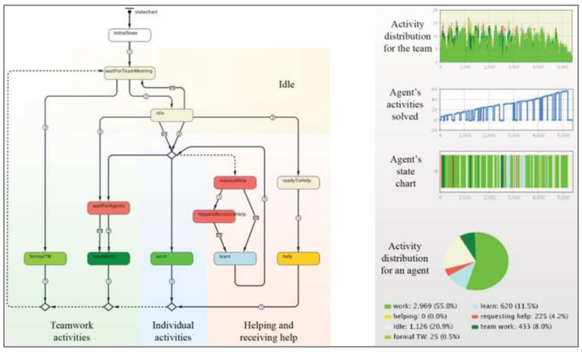

Figure 6. Basic agent-based model flowchart and outputs

4. Conclusion

Several benefits can be derived from results of the research so far. First, the network of the performance indicators is pointing organizations toward the measures that should be applied to validate the individual and teamwork performance. Proposed framework enables the understanding of the main drivers of change in the performance indicator values over the time and recognition of the emergent organisational risks. Information obtained by framework application in real-world organisation context can indicate the positive or negative trends in the monitored project, emphasizing socio-technical aspects, which are often neglected in current management practice. Also, the simulation of teamwork can be used as a proactive tool for R&D project management. The simulation implemented as a management tool can help managers in the planning of the team composition and customization of the activity workflow within the development process.

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