SOCIOTECHNICAL SYSTEMS ACCEPTANCE AND SUSTAINABILITY ASSESSMENT USING DYNAMIC SIMULATION MODEL

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ABSTRACT
Since the creation of sociotechnical systems Integrated Acceptance and Sustainability Assessment Methodology (IASAM) in 2013 it has experienced several levels of upgrade. Each next step of improvements has mainly added new dimension and increased the potential of applications of the methodology. In addition, a web-tool was created for the first version of IASAM and this was also improved along the changes of methodology.

Keywords: IASAM3, acceptance and sustainability assessment, sociotechnical systems, system dynamics

1. INTRODUCTION

The prevalence of technologies in our everyday lives keeps increasing and so does the number of devices and gadgets around us. Technologies are being embedded in most processes underlying our work, education, travel, entertainment, etc. However social pressure of society resulting in technologies changes and initiates the new and combined solutions related with RFID, VR/AR, Future Internet, OCR applications, etc. This has not only led to development of complex sociotechnical systems, but also to the evolution of acceptance and sustainability research. The complexity, in turn, makes the development, requirements definition, testing and the analysis of eventual adoption and diffusion of sociotechnical systems very difficult.

The complexity makes also the sociotechnical systems research field highly multi-disciplinary. According to Morris (2009) there are at least four differing viewpoints in the literature about such systems and they represent the interdisciplinary research conducted in social sciences, organizational sciences, engineering, and complex systems.

Complexity can be explained by the logical and physical structures of sociotechnical systems, where first one involves ideas, concepts, guidelines, rules, algorithms, but second - environment (technical ones and persons) for implementation and running of logical structure (Ginters et al 2017). Typical features of sociotechnical systems are their emergent properties (some of the properties of the system emerge after it has gone into use and cannot be predicted in advance), their non-deterministic nature and the fact that they are influenced by the organisations culture, rules and objectives (Somerville 2014). The term sociotechnical systems is widely used to describe many complex systems, but there are five key characteristics of open sociotechnical systems (Badham et al 2000):

- Systems should have interdependent parts;
- Systems should adapt to and pursue goals in external environments;
- Systems have an internal environment comprising separate but interdependent technical and social subsystems;
- Systems have equifinality. In other words, systems goals can be achieved by more than one means. This implies that there are design choices to be made during system development;
- System performance relies on the joint tuning of the technical and social subsystems. Focusing on one of these systems to the exclusion of the other is likely to lead to degraded system performance and utility.

Sociotechnical systems involve complex interaction between people, machines, and the environmental aspects of the work system (Baxter and Sommerville 2011). The involvement and participation of people significantly affect the architecture and design of those systems (Reymondet 2016). These systems usually contain technology subsystems and components central to its performance and have societal, political, and economic relevance and impact (Susmann 2013).

Therefore, it is necessary to understand and assess emerging sociotechnical systems. Especially nowadays, when technologies develop in a rapid manner and technological changes can often disrupt a market or industry's established rules, living conditions, orders, beliefs, and values. Organizations will succeed only if they are able to embrace the change (Jonathan and Chung-Shing 2015). But organizations and their management often does not have the capacity to cover the main insights of several disciplines and make an informed decision with limited time and knowledge resources and without comprehensive methodology. The decision makers need tools to evaluate sociotechnical systems and become aware of the new reality.

Furthermore technological change and innovation is itself at the center of many research papers (Jonathan and Chung-Shing 2015, etc). One of the issues that the developers of technologies, researchers and organizations are most interested in is the potential adoption (and acceptance) of the technology and its diffusion within society and the consequent success in the market. Technology acceptances are information service theories that model how users come to accept and use a specific technology. These theories suggest that when users are presented with a new technology, a number of factors influence their decision about how and when they will use it (Samson and Jongsu 2015).

Many authors have studied different aspects of new technology acceptance from a variety of theoretical perspectives explaining the relationship between user beliefs, attitudes, and intentions and analyzing different factors that influence information technology acceptance – individual, organizational aspects, cultural, gender and professional differences. These studies focus on behavioral aspects of technology acceptance or adoption, for example Theory of Reasoned action (Fishbein and Ajzen 2010). One of prominent models to be mentioned is Technology Acceptance Model (TAM) (Davis, Bagozzi, and Warshaw 1989). It has been criticized for focusing on initial adoption and not on continuous use. There are also other approaches, for example Expectation-Confirmation Theory (ECT) (Bhattacherjee 2001) that initially originated in marketing sphere and Unified Theory of Acceptance and Use of Technology (UTAUT) that tries to consolidate eight approaches into one (Venkatesh et al 2003). These theories question the factors behind the intentions and behaviors of users from psychological perspective. Different variations of TAM, UTAUT model, ECT and some others are mentioned in the discussion of technology acceptance and adoption research.

But none of them gives full and combined understanding about the human and technological factors that are influencing acceptance and sustainability of sociotechnical systems.

The aim of the research underlying this paper is to create a comprehensive tool to help interested stakeholders to embrace the change brought by technology innovations and to analyze the acceptance and sustainability of emerging technologies.

The authors propose the concept of sustainability for evaluation of the set of factors that let the technology to be developed, implemented, maintained properly (i.e. according to the needs of all stakeholders) and attract long-term users and create positive output and/or outcome according to the purpose of the technology and initial intentions of its developers (financial, social, etc) (Aizstrauta, Ginters and Piera Eroles 2014). Technology sustainability thus combines the different ways for looking at technology development, acceptance and diffusion, and fills the gaps in the literature. Because the understanding of technology development and exploitation is increased by combining individual factors with both internal (connected with ICTE development management and quality of technology) and external (connected with domain development) sociotechnical factors.

For measurement of potential acceptance and sustainability an IASAM was created in 2013. It is a methodology that helps to evaluate technologies from four perspectives, called flows – management, quality of technology, acceptance and domain development. This evaluation approach is based on a viewpoint that technology acceptance research should not be divided apart from the technological, economic and social evaluation. In other words it introduces a new approach for evaluation of new technologies by combining socio-economic aspects and technical characteristics of technology development and exploitation (Aizstrauta and Ginters 2015).

The following sections of this article are organized as follows. The next section describes the development of IASAM3 and the underlying reasons from several upgrades making the IASAM more experienced. It also describes the fundamentals of using IASAM3 methodology. The third section then explains the role of system dynamics simulation to build an interactive IASAM3 tool. Finally, the conclusion contains a summary of the main ideas of the paper.

2. DEVELOPMENT OF IASAM3 AND THE APPLICATIONS OF METHODOLOGY

In terms of content and themes to be covered the research on technology sustainability and acceptance evaluation was driven by the need to understand, how technologies, people, organizations, policies, and societal values are intertwined. It was clear that to satisfy this need a tool had to be created that would include technical and human factors assessment. But sociotechnical systems are governed by organizational policies and rules and may be affected by external constraints such as national laws and regulatory policies (Sommerville 2014). Also Reymondet (2016) points out that in sociotechnical systems research, the dichotomy between the technical on one side, and social and human on the other side is salient. Therefore the research had to look further and widen the scope of factors under assessment to create a methodology that identifies measures and arranges the criteria that impact technology's sustainability and cover a wide range of issues. All these dimensions are built the IASAM3 index.

In terms of structure the tool had to meet certain prerequisites. Namely, the integrated acceptance and sustainability assessment model had to:

- Be easy accessible to use and available to different stakeholders with different experience

and knowledge, from inventors and programmers to potential investors;
- Be usable for initial evaluation as well as within later stages of technology development;
- Offer an opportunity to analyze and assess the anticipated dynamics of the evaluation results. Thus, the assessment model can be used also as guidelines for technology development.

2.1. IASAM Development from the First Version to IASAM3 - Reasons and Benefits

Since the creation of IASAM methodology in 2013 it has experienced several levels of upgrade. Each next step of improvements has added new dimension and increased the potential of applications of the methodology. In addition, a web-tool was created for the first version of IASAM and this was also improved along the changes of methodology.

At the first level, the methodology was just a set of 49 questions that were grouped according to the model's criteria. The initial IASAM version was validated against Skype as it met the indications of a successfully implemented technology (Aizstrauta, Celmina and Ginters et al 2013). Then IASAM was used for socio-technical evaluation of actual products within FP7-ICT-2009-5 CHOReOS project No. 257178 (2010-2013) *"Large Scale Choreographies for the Future Internet (IP)"*. Within this project eight products were evaluated. The results gave some understanding of the technology and its development process, but the result lacked dynamics and its interpretation was rather narrow.

But the most important flaw of this version was that the model included a survey of potential users that was based on UTAUT model and that was a burden for the users of the methodology. The methodology is planned to be applicable at any stage of technology development and potential user surveys might be very challenging during early stages of technology development where no prototype is available, in cases were potential users are hard to reach or in situations when there is no time. Such a survey would need either excessive time, human or financial resources.

Therefore IASAM2 replaced the potential user survey with additional criteria that are based on attributes of innovations based on Rogers (2003) Theory of innovations. This resulted in a model that consisted of 61 questions that remain grouped under 17 variables that together constitute four main groups, called flows, that make up the result. Additional validation measures were taken, again using Skype.

This version was applied within another international project "Future Policy Modelling" (Ginters et al 2013), where four products were assessed using IASAM2 methodology.

The IASAM2 version had several significant benefits, including that the assessment could be carried out by the interested party oneself, there was no need for resource-consuming potential user survey. Besides, the model itself became more comprehensible, as the calculus, analysis and reporting could be done within one methodological framework. This version of IASAM2 met the initial goals of this methodology to make it better – it became easier to use and more universal in its applications.

Later on the methodology was improved once more and the functionality and respective advantages of system dynamics simulation were incorporated within the model. With the help of mathematically reprocessed life-cycle data of other technologies the static IASAM2 was reshaped into a dynamic analytical tool that helps not only to evaluate the current condition of the technology, but also to make judgements on potential life cycle parameters at any step of development the technology under assessment. It was done using Skype as a "role model". That means that the assessed technology IASAM3 reference trendline is being compared with Skype's life-cycle function and therefore, the measurements done with IASAM3 methodology became comparable with reference trendline and the sustainability and acceptance of Skype. The technology assessment results can now be viewed and interpreted in contrast with the results of Skype. Such approach makes the results of IASAM3 more comprehensible, enable less complicated interpretations, and be more user-friendly (Aizstrauta and Ginters 2017).

2.2. IASAM3 Methodology Fundamentals

From the very beginning the use of IASAM3 methodology was intended to be relatively easy. The basis for the assessment is a self-assessment questionnaire. The developer or any other stakeholder or interested party can do the assessment, using available information and his or her subjective attitude. To reduce the subjectivity of the assessment, it is advisable to use information from internal procedures, employee evaluation, client surveys, etc.

And the sources of information that is needed for the evaluation are omnifarious – the information can be:

- Described or embedded in the documents of the organization;
- Embedded in processes connected with the development or running of the technology;
- Publicly available sources about the company or the overall market situation;
- Ascertained with the help of people involved in the technology development.

IASAM3 index is made of four basic flows – management, quality of technology, technology acceptance and domain development. Each of them consists of certain criteria – all together eighteen criteria. Each criterion is evaluated with the help of specially formulated criteria descriptions/statements. That means the user evaluates 61 pre-defined criteria descriptions using a simple 7 point Likert scale. The evaluation of criteria is undeniably subjective, but it relies on assumption that every evaluator, whether a technology developer or potential investor, will be concerned to receive the most reliable evaluation for decision-making. After the criteria have been evaluated the sum of all values from the questionnaire is calculated and divided by maximum possible value of questions answered. The result gives a numerical value of integrated technology sustainability index

$$IASAM3_{index} = \frac{\sum_{n=1}^{12} F_n + \sum_{i=1}^{49} B_i}{(N - C) * 7} \quad (1)$$

, where F – additional IASAM2 survey response values; B– initial IASAM survey response values, N – total number of questions; C – number of questions marked with “N/A”.

In addition, the procedure calculates the consistency of the result. This value E is called IASAM3 credibility and it looks at the number of questions left when C values (those marked with N/A) are excluded and decreases the „internal credibility” of the index calculated in the previous step. The more questions marked with N/A the less consistent is the result. The E is calculated as:

$$E = C / N \quad (2)$$

, where E – credibility, N – total number of questions, C – number of questions marked with N/A.

Thus the measurement gives two results – the sustainability index of the assessed technology and the credibility for the calculated index. Besides it is worth mentioning, that model allows making evaluation multiple times during the life-cycle, gathering these results and comparing the evolution or development of the technology from IASAM3 perspective.

The final value of the IASAM3 index indicates the percentage of the potential maximum that could be reached in comparison with the Skype. Therefore, the next step is to construct a trendline of evaluated technology and use it to compare the potential dynamics of IASAM3 index in comparison to Skype reference trendline. This trendline is constructed using a polynomial function (3):

$$IASAM3_{reference-trendline} = 2.5327x^3 - \\ -7.1021x^3 + 4.6355x - 0.0485 \quad (3)$$

The polynomial function is a result of mathematically reprocessed life-cycle data of other successive and wide used technologies to predict continuation of the Skype life-cycle in conformity with IASAM3 rules. Its aim is to reshape the static IASAM2 into a dynamic analytical tool that helps not only to evaluate the current condition of the technology, but also to make judgements on potential life cycle parameters of the technology under assessment. Finally by the aid of interactive visualizations applicant can make many experiments using different what-if scenarios.

3. SYSTEMS DYNAMIC USE FOR TECHNOLOGY ASSESSMENT USING IASAM3

System dynamics discipline is an attempt to address the changes of an ever increasing complexity of everyday life and long-term policy problems. Applications of system dynamics cover a very wide spectrum, including national economic problems, supply chains, project management, educational problems, energy systems, sustainable development, politics, psychology, medical sciences, health care, and many other areas (Barlas 2002; Nielsen and Nielsen 2015).

But dynamic complexity and the interdisciplinary policy problems are often embedded in or rely on sociotechnical systems, therefore system dynamics approach is suitable to address problems connected with sociotechnical systems research.

In addition, as Nielsen and Nielsen (2015) put it, the system dynamics does not offer one “grand theory” instead each model is a theory by itself. And therefore IASAM3 is a model that is a theory of acceptance and sustainability assessment of technologies.

The concepts of the system dynamic philosophy are primarily centered on a certain understanding of causality in a system’s setting. System dynamics is concerned with aggregate social phenomena and not individual actions (Nielsen and Nielsen 2015). The simulation approach provides the opportunity to analyse a time-varying system with multiple feedback links and analyze quantitative and qualitative factors (Ginters, Barkane and Vincent 2010)

The simulation and modeling tool Insight Maker has been designed to make modeling and simulation accessible to a wider audience of users and integrates three general modeling approaches – System Dynamics, Agent-Based Modeling, and imperative programming – in a unified modeling framework. The environment provides a GUI that is implemented purely in client-side code that runs on users’ machines (Fortmann-Roe 2014). Therefore Insight Maker was selected as simulation environment of IASAM3.

3.1. IASAM3 Tool and Case Studies

For the purposes of IASAM model application, a custom made web-based evaluation tool was created for the initial IASAM version. It’s approbation is described in the documentation of CHOReOS project “Large Scale Choreographies for the Future Internet” (2010-2013). Later the tool was improved following the model advancements and now offers the users not only to carry out evaluations, but also use Insight Maker as a system dynamics modeling platform. This tool enables the users to:

- Create evaluations in a user-friendly, intuitive environment;
- View the results of IASAM3 index of evaluated project or technology;
- Visually compare the results with Skype life-cycle;
- Change the values of indicators in an interactive environment to run different what-if scenarios.

Two case-studies were used to test this new approach and the web tool – one of improvements of technology that calculates the plays of poker game (project "Poker Calculator") and another of implants that simplify the communication with computer with the help of user's hands (project "Implants").

First, the documents, procedures and responsible persons that could provide information for evaluation purposes for each case study were identified and the information was gathered. Second, the self-assessment questionnaire was filled out and the IASAM3 index of the evaluated project was calculated according to the answers of the questionnaire. Then, according to the new perspective added by IASAM3 compared with IASAM2, Skype reference trendline is constructed (3). IASAM3 index indicates how the function of the technology under assessment looks pro rata. The function for the technology under assessment is constructed by scaling the function on both axis.

Further the web-tool lets to change the values of four main flows – acceptance, quality of technology, management, and domain development – and run InsightMaker based simulations to test different scenarios. The process is visually described in BPMN2 notation in Figure 1.

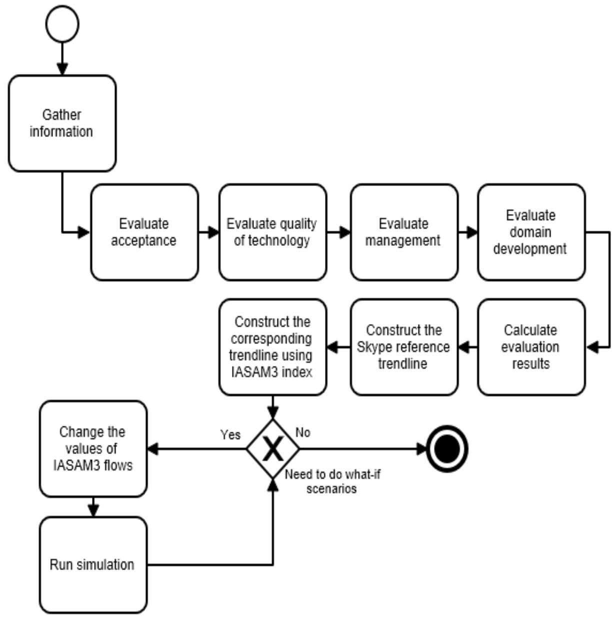

Figure 1: IASAM3 Implementation

Graphical results of simulation one case studies can be seen in the Figure 2 and Figure 3.

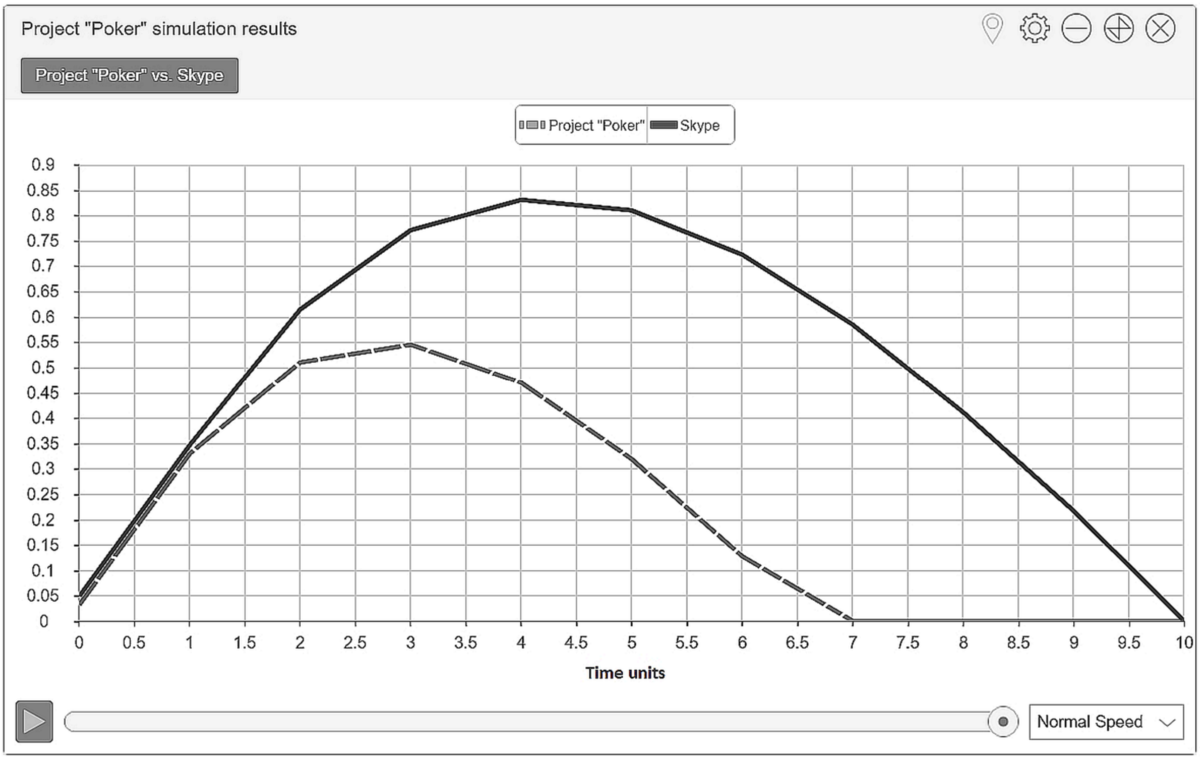

Figure 2: Project "Poker Calculator" Results Generated by Insight Maker Engine within the IASAM3 Web-tool

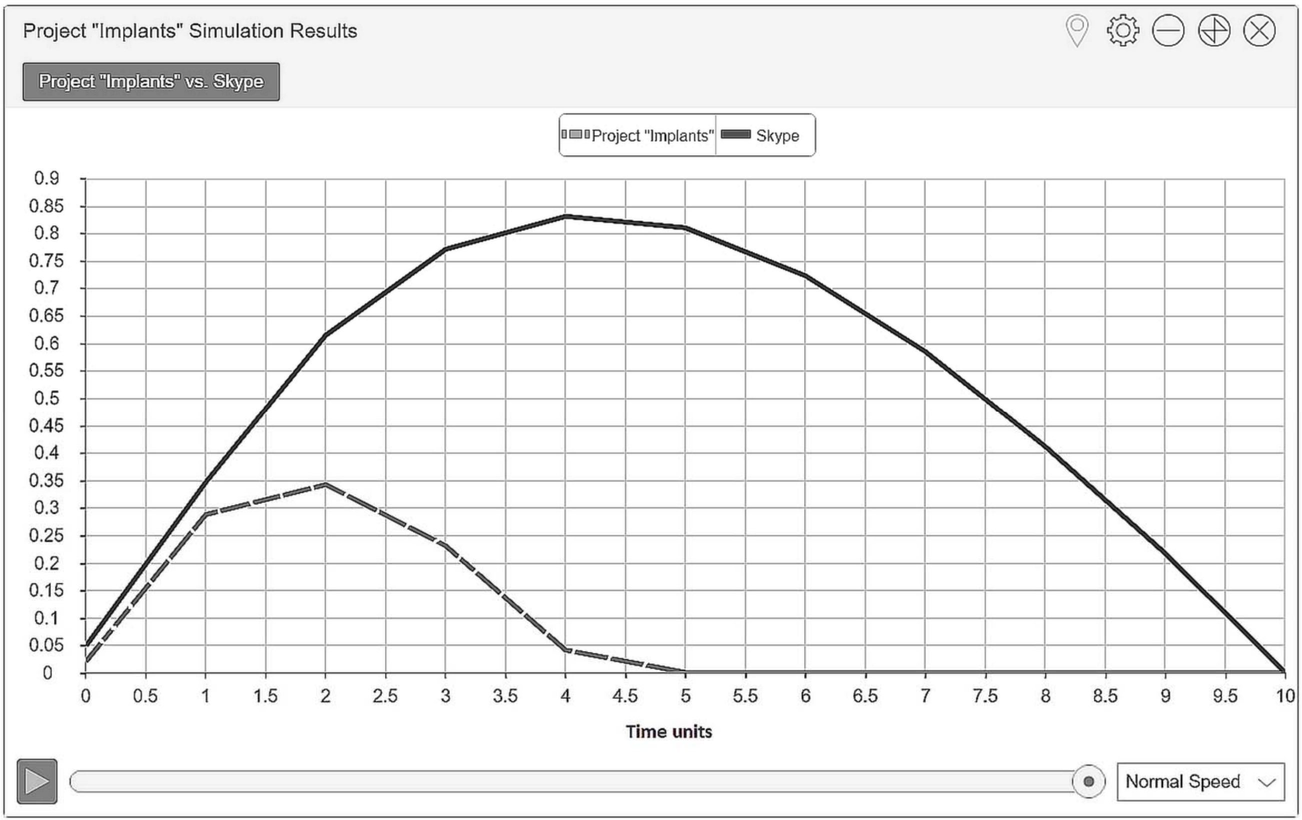

Figure 3: Project "Implants" Results Generated by Insight Maker Engine within the IASAM3 Web-tool

The result of the poker calculator shows that the technology complies with the development cycle of Skype with IASAM3 index value 0.67. That means that the technology will be able to reach 67 % of Skype's theoretical maximum. The implants on the other hand reach 47 %.

The tool enables the user to manually change the influencing values of IASAM3 index (1), by changing the value four flows – key impact factors – management, technology acceptance, quality of technology and domain development (see Figure 4). The main elements of the interface are:

- InsightMaker panel which shows the IASAM3 model's graphical visualization;
- Visualization the results of simulation within the same InsightMaker panel;
- The numerical result of the simulation, namely, IASAM3 index and Credibility values on the right side;
- Custom made sliders for adjusting the value of four flows for the simulation of what-if scenarios also on the right side;
- Web-tool management menu on the upper side of the panel.

By repeatedly running the simulation the predicted life-cycle trendline of the evaluated project is calculated according to the new values and shown in a graph, also including the Skype life cycle trendline as a reference.

4. CONCLUSIONS

The increasing amount of technologies that define more and more aspects of our everyday lives has led to a massive spread of different technologies, including complex sociotechnical systems. The human factor involved in every sociotechnical system makes these systems and their outcome both more valuable (these systems cannot yet be substituted by technical solutions) and more complex (they are harder to build, predict and exploit).

Sociotechnical systems are interdisciplinary in their nature and therefore need an interdisciplinary approach in their research. IASAM3 methodology proposed by the authors offers an interdisciplinary assessment methodology and a web-based tool to evaluate the potential acceptance and sustainability of technology. The methodology combines the technical criteria of technology and its quality itself, the human factors of technology adoption, the socio-economic aspects. During the development of IASAM3 it has been through three development stages and has resulted in a tool that can help the interested stakeholders to get a well-founded evaluation that shows also the prospective success of the technology.

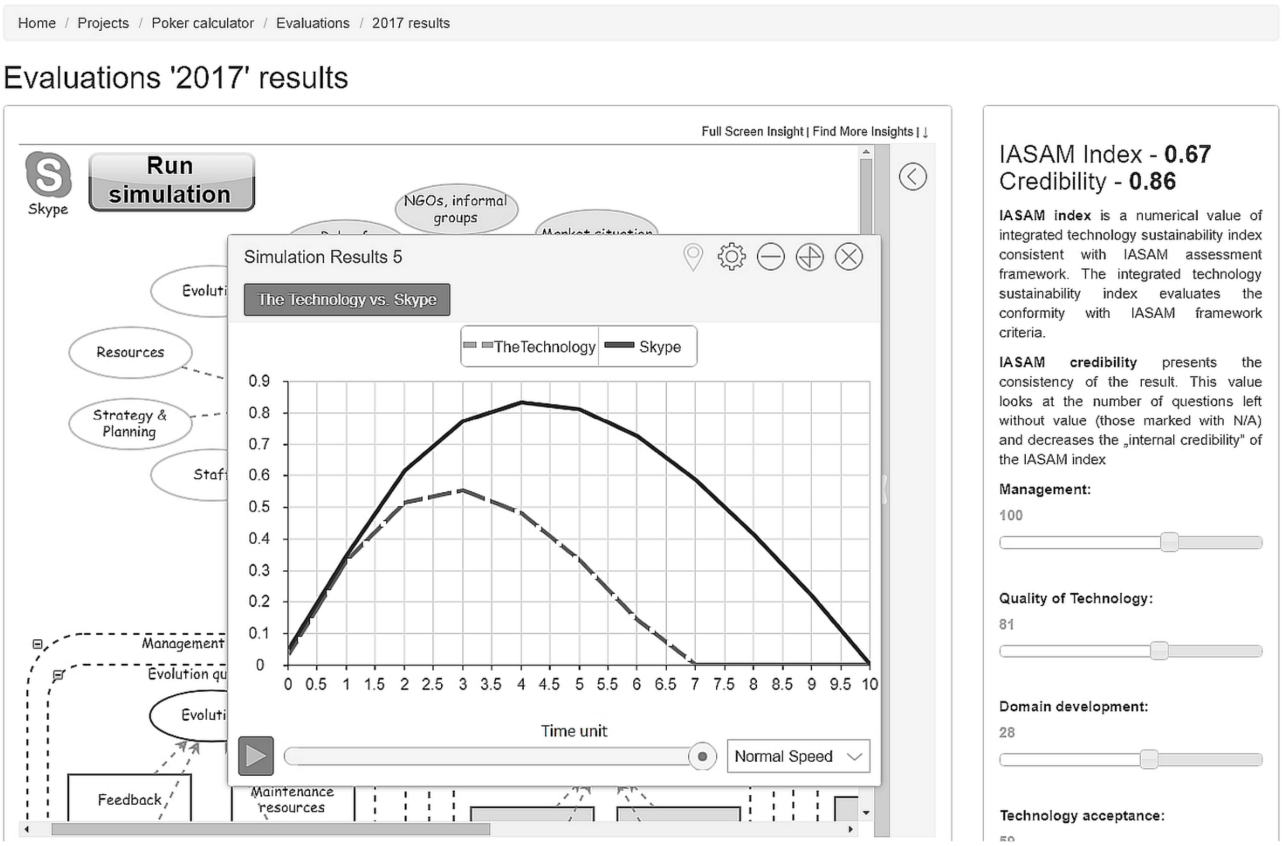

Figure 4: Screenshot of the IASAM3 Web-tool's GUI

IASAM3 adds to the evaluation results perspective of time that is displayed in the context of Skype life-cycle path. By showing visualizations of two functions, this tool makes the result more intuitive and easier to comprehend. System dynamics and InsightMaker simulation platform enable the user to carry out deeper analysis of the results.

Additional benefit of IASAM3 is that it provides users with a ready-to-use and user friendly tool that does not require additional specific knowledge in the field of modeling, programming, or statistics.

Therefore, it can be used as widely available open source tool across specialists with different backgrounds.

To ensure the availability of this tool to as many interested parties as possible, it is easy accessible and is provided as a ready-to-use software. Even more, it could become used as the "software on-demand". The Software as a the Service (SaaS) lets the companies to avoid traditional software installation, maintenance and management steps in favor of delivering cloud-based applications via the Internet. However the aspects of IASAM3 tool to become a SaaS needs additional deliberation.

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