Introduction to Technologies Acceptance and Sustainability Modelling

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ABSTRACT

Elaboration and introduction of a new technology is a complex and expensive task, therefore it is necessary to assess the set of factors influencing the future of technology. The most important parameters of assessment are acceptance and sustainability of technology. Different models exist, but mostly they are static and do not offer possibilities for interactive and real time assessment and do not allow forecasting the sustainability of technology. In the framework of FP7-ICT-2009-5 CHOREOS project No. 257178 a new two step methodology, Integrated Acceptance and Sustainability Assessment Model (IASAM), of socio-technical assessment has been elaborated.

INTRODUCTION

Technology acceptance and sustainability assessment is vital for technology developers and investors in the decision making process because of the limited availability of development and deployment resources. The result (technology acceptance, sustainability and investment returns) is determined not only by the quality of the technological solution, but also by social and economic factors which developers often cannot or can only partially influence. These can change as technology evolves, therefore the necessity can arise to reevaluate the expected result and make decisions.

Recognizing that technological growth can lead to changes in economic structure, environmental balance and social structures, technology adoption and sustainability assessment is necessary not only to investors and developers. Government and non-governmental organizations, as well as groups of users make decisions that may affect the further development of technology. Interest groups want to defend their interests by moving technological development in their preferred direction.

The concept of technology involves at least two interrelated meanings. Firstly, technology refers to the logical (processes, procedures) and physical structure - both tangible and intangible objects that serve as an environment for realization of the logical structure. Secondly, technology refers to the technical knowledge which may be either general or already covered by specific artifacts (Bergek 2008). The inclusion of social factors (technology acceptance, the formation of user opinions and business processes) to assess technology allows to analyze technology adoption and distribution processes.

Every technology life cycle has at least two stages. The market environment is researched and a conceptual model of the solution is developed. Perhaps some experimental designs are developed and the evaluation of various technological effects continues. With some probability it is possible to evaluate whether this technology will gain support among potential users, that is, the adoption of technology is simulated and possible projections and recommendations are prepared. If the prognosis indicates a potentially positive outcome, a pilot solution is prepared and selectively implemented, therefore allowing for a more precise evaluation of the expected results of technology acceptance. These are more or less static methods that can be used during the first steps of technology development and implementation.

However, above all, investors are interested in the sustainability of a technology which depends on a set of variable and difficult to measure parameters. The above mentioned problems dictate the creation of a multi-level system dynamics real-time model that respects not only the technology acceptance options at the beginning of the life cycle but can also be used to interactively predict the sustainability of technology.

There are various technology adoption solutions of which the most popular are TAM, TTF, UTAUT (Zhou 2010) and other models. Technology sustainability assessment methods lag behind and the offered solutions (Chandak 2007) are static and do not offer iterative and interactive options to simulate changes at any point in the technology development process.
Technological sustainability can be assessed in two main directions:

- The impact of technology on social, economic and environmental sustainability by analyzing what positive and negative changes technological development and usage can cause in the environment. Such an assessment should be carried out in the public interest;
- Assessment of the sustainability of technology by analyzing the possibilities of technology development, technology transfer, acceptance and intensity of use, and, above all, the financial benefits of technology application to its developers, investors and the public.

The success of technology transfer can be measured and evaluated from a number of perspectives. Economic growth and competitiveness are expected at the national level, firms look at profit and market share, venture capitalists focus on return of investments, consumers want new and useful products and R&D performing institutions value revenues from patents and licenses (Karlsonn 2004).

The assessment of technology sustainability is complicated by the multilayered nature of technology development and distribution processes. Technology development involves several interrelated processes. The creation and distribution of knowledge forms a knowledge base for the development of new and alteration of existing technologies. Entrepreneurs and business entities get involved in the making of new products and services, and their marketing.

Governmental and non-governmental organizations assess technology trends, therefore supporting or inhibiting the development of a trend. In order to ensure adequate resources for development, it is necessary to attract investors who, in return, want to be assured of the security and return of their investments. Social, economic and technological factors may change during the development of technology. Consequently, technology developers and investors need the opportunity to determine the sustainability of the technology at any level of technological development. This would allow them to make decisions in response to changing external and internal conditions. Decisions may affect technology trends and, possibly, technological development will lead to changes in external environmental factors which, in turn, will affect the previously planned technological developments.

The authors use system dynamics methods for process specification and simulation. This provides the opportunity to simulate a time-varying system with multiple feedback links and analyze quantitative and qualitative factors. Technology sustainability assessment and the related process model are created using the system dynamics simulation environment Stella (STELLA 2004).

The above mentioned approach allows describing technology development as a set of parallel processes. This set is characterized by:

- Socio-technical features of the system (dual nature: technical plus social and / or environmental factors);
- Development in a specific period of time;
- Involvement of multiple decision making entities, such as companies, institutions and individual consumers;
- Set of variable measurable factors, for example, number of users, total value of investments, market volume;
- Set of relevant internal and external factors that impact the trends of individual change processes;
- Possibility to append or replace parameters.

TECHNOLOGY DEVELOPMENT

Economic and technological processes – the drivers of progress

Technology sustainability studies that analyze technology development (change) possibilities, taking into account technology transfer, acceptance and intensity of use, often highlight the financial result of technology development for developers and investors as one of the key issues.

The key points of economic theory used in the creation of a technology development model structure are as follows:

- System participants learn from past events and decisions shall be guided by their subjective beliefs about the future;
- There is an evolutionary process - there is no strong advantage and no common goal;
- Developments and their assessment is influenced by the existing economic, social and political structures, as well as traditions;
- Rationality and forecast reliability is limited because of the lack of information, furthermore, available information is not always reliable;
- There is inertia and opposition to alleged activities in the system.

Various resources (human resources, equipment and devices, infrastructure, material) are needed to ensure technological development. Their acquisition is possible only if financial resources are available. Financing is possible as:

- Self-financing – funding technology development from its sales (licenses, patents, products);
- Investment funding - attracting external capital.

At the beginning of technology development, usually only investment funding is an option. Self-financing becomes available above a certain level of development which allows for the sale of values generated by the technology.

Lending availability and price of money (interest rates), as well as the opportunity to raise funds through membership in a company, depends on the overall economic situation and the attractiveness of the technology to investors which is determined by the potential market value of the technology and possibilities for technology commercialization, i.e., to create products that meet market demand.

Technological change model

Geel created a dynamic multi-level socio-technical change model that depicts the formation and distribution of new technologies and the related changes in technological, social and economic environments, emphasizing the importance of technology niches.

The environment in which technology development and use happens is analyzed on three levels:

- On the micro level technologies develop in small technological or market niches where they are protected from the influence of the mass market. As a result the proposed solutions can be refined. While being developed simultaneously, technologies compete with each other, knowledge is transferred, imitation happens, competing technologies come together and form a dominant technology that can operate and compete in the mass market;
- On the micro level socio-technical regimes are formed by a network of social groups and laws that stabilize the existing technologies and, to some degree, provide inertia of the regime;
- On the macro level the environment (landscape) functions outside niches and regimes, however various aspects (culture, style, changes in infrastructure) can put pressure on the micro level thereby allowing its inertia to weaken and opening opportunities for new technologies to enter the mass market (Geel et.al. 2005).

These studies showed that technology cannot develop without support structures. To become part of a socio-technical regime positive macro-level factors, which provide for a weakening of the current technology regime, are also necessary.

Technological change depends on the existing socio-technical environment, the current technologies and the strategic decisions made by the developers of the new technology. Factors are different in each case and they create a distinctive dynamic in internal technological environment change processes. However, there are groups of factors that can potentially have an effect on technology development.

Consequently, a concept model can be created including factor groups and processes, which are further specified for the technology that is analyzed – by adding concrete, measurable indicators and determining impact coefficients.

Technological innovation systems

Technological innovation systems research is based on innovation systems theory. The basic idea of innovation systems theory - innovation and process changes are not determined by the activities of one company or research body. They form because of extensive changes in social structures. (Suurs 2009). Innovations have long been studied as a gradual, linear process in which knowledge creation (research) transforms into applicable consumer products and ends with production, and the diffusion of innovation. Each stage in the linear innovation model is examined in time, as well as in regard to the parties involved (actors).

The basis of innovation systems theory is the co-development of all processes providing feedback functions and stressing that only by achieving unified system development innovation, industrial transfer and economic growth is possible. As an essential prerequisite for development, positive feedback loops and the system are being analyzed. The innovation system approach is the basis for policy design in various regional and national strategy-forming organizations (OECD, the European Commission and UNIDO) (Bergek et. al. 2008).

Technological innovation systems are defined as "a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (Suurs 2009).

Consequently, innovation systems are not confined geographically or within an industry. New technologies may develop at contact points between various sectors. The aim of innovation systems is to recognize, develop and implement business opportunities, making technological innovations economically viable. Innovation and consumer products grow out of knowledge and information flows, and reach a certain level of knowledge. This is the basis for a business, which is able to convert this knowledge into specific products or services. For the technology to reach its users, technology market formation starts along with its development. Market formation is influenced by business activities, government and non-governmental organizations with grants and tax policy.

Innovation systems participants (actors) are any number of people who, with their knowledge, skill or resources, are directly involved in technology development and use (companies, research centers) or indirectly provide support for technology development (donors, governments). Rules and standards, in place in the early stages of technology development, may not comply with the possibilities or needs of the new technology. The development of clear and appropriate standards and terms is one of the processes that stimulate innovation systems development. Innovation systems are categorized into eight basic functions (Bergek et. al. 2008):

- Encourage businesses to engage in innovative activity;
- Provide necessary resources (capital and expertise);
- Manage research and development progress by influencing the direction in which available resources are invested;
- Identify possible directions of growth (technological feasibility and economic viability);
- Promote the sharing of information and knowledge;
- Promote and / or create market structures;
- Reduce uncertainty and promote society confidence about the new technology;

- Neutralize, reduce possible counteraction to new technology.

The technological innovation systems approach analyzes technology development sustainability based on support, creative and distribution processes of the technology. However, an essential factor of technology is the ability to define its created and added value in a way that is important and understandable to the user. The potential user assesses the new technology by comparing to which extent it is able to offer a better (financial, time, convenience, availability, security, etc.) solution to ones needs (present or future) than the current, competing technologies.

Technological development as a result of innovation

Utterback (Utterback et. al. 1975) identified three stages of technological innovation research.

In the initial, uncoordinated stage, while parameters and specifications for the product are being developed, productivity is low, but market competition is based on the properties of the product. Since the production processes and regulatory standards have not yet been developed, product development changes are easily carried out, but production costs are high at this stage. This coincides with the technological change model (Geels 2007) - initial commercialization opportunities should be sought in specific niches by offering new technology to consumers who are able to analyze and evaluate certain specific characteristics, and are willing to pay more.

As a result of the uncoordinated process, being influenced by the users, taking over and modifying their own and competitors' ideas, by standardazing the manufacturing process, a dominant design is formed (the best possible product in that situation). The segmental development phase begins. Innovations in processes related to the products manufacturing and distribution increase rapidly. Processes are mutually coordinated and, because developers shift resources to process innovation, product innovation rapidly decreases. By the end of this stage, manufacturing companies have introduced complex technologies that provide an economically feasible production of a product, low cost of the finished product and adequate capacity to meet growing demand. The products user base grows rapidly. The systemic phase begins in which complex, integrated production processes are closely linked to product design, so that any changes in design will cause the need to change production processes, and vice versa. Production is increasingly standardized, achieving increasingly higher volumes and lower cost.

One of the most important conclusions of Utterbacks' approach - internal processes and their flexibility within the developers' organization have a significant impact on technology development. In the 1980-ties this corresponded to the existing production and market structures, since there was an opportunity to fix a relatively stable model of the dominant product, gaining profits and income mainly from long-term mass production, when only minor changes are made to the product to maintain or increase turnover.

21st century technologies evolve continuously, production systems have become increasingly flexible, and as a result, this model shows the main risks – by standardizing products and creating inflexible innovation or manufacturing processes within the organization, the opportunity to produce more and cheaper is achieved, but this limits the further development of the product, which creates problems in technological competition.

However, there are limits to the development of every technology because no solution can be perfected indefinitely (see Figure 1 and Figure 2). The above mentioned improvement development simulation model in STELLA notation is depicted in Figure 1.

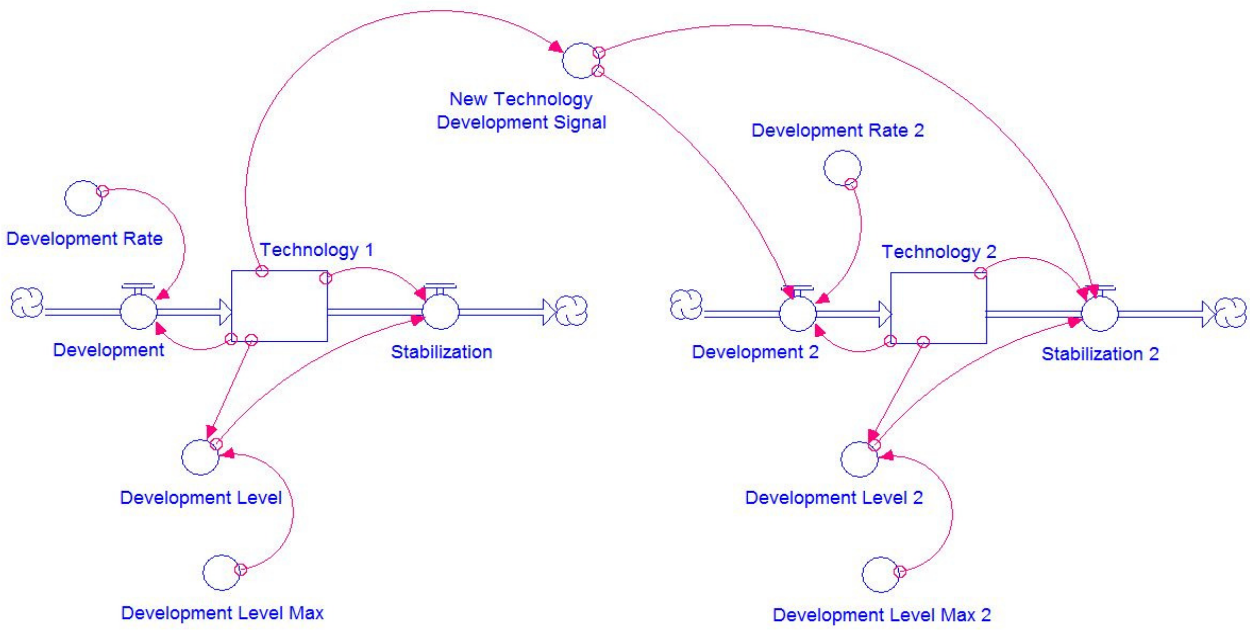

Figure 1: Technology development and replacement model.

For example, the ways to improve a residential building will be determined by its foundation. However, a technology is developed in parallel with the formation of new technologies whose performance initially is lower, but the basis of these new technologies is a higher technological frontier (Nikula et.al. 2010). Therefore it is sometimes possible to develop new technologies on the ruins of older ones, for example, by taking over competitive solutions (see S-type curve in Figure 2).

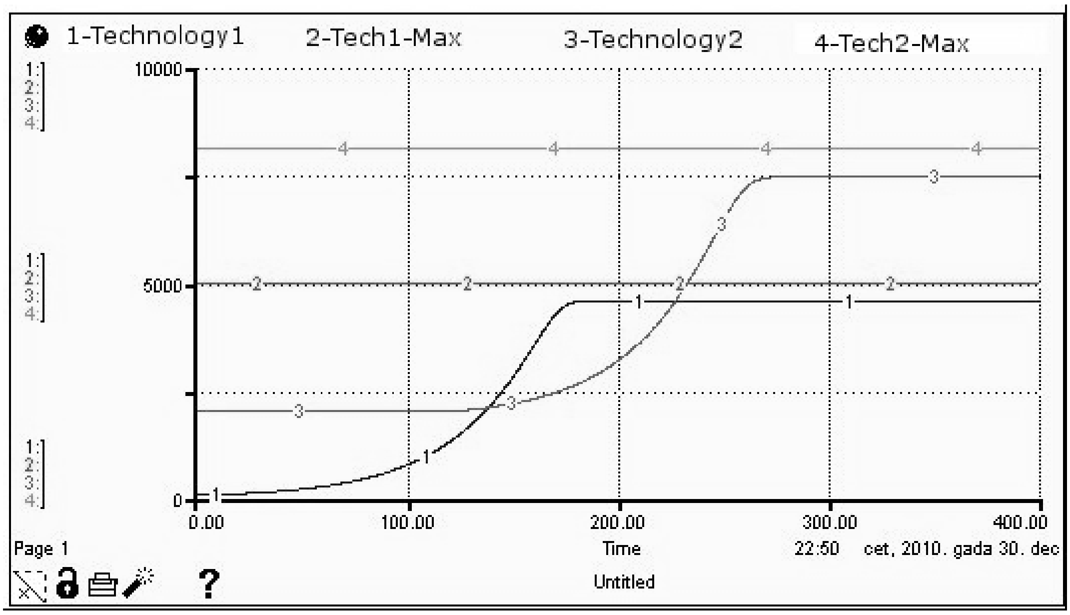

Figure 2: Development model of two competitive technologies.

A technology development state, which can be characterized by low cost, standardization and relatively low investment return rates, shows the achievement of stability in technology development. External factors - new technological opportunities, changes in demand, changes in the economic situation can create a signal for the beginning of development of a new technology and bring about the beginning of the end of the existing technology, or give rise to qualitative changes in the existing technology (see Figure 1).

TECHNOLOGY ACCEPTANCE SIMULATION – A PREREQUISITE FOR SUSTAINABILITY ANALYSIS

Classical innovation diffusion theory

Technology can only be sustainable if it is accepted and used by users. The users and potential users of technology subjectively assess the technology and compare it to possible alternatives. Information technology acceptance and usage studies have a number of known approaches to analyze the technology adoption process.

The technology life-cycle acceptance and innovation diffusion model is known in the field of classical marketing (Rogers 1995). The model describes the adaptation of innovation guided by demographic and psychological characteristics of groups, and offers five adaptation target audience groups:

- Innovators - highly educated, wealthier and more risk-oriented people;
- Early adopters - young, educated people, who aspire to be leaders;
- The early majority - more conservative, but open to ideas and active in the community;
- The late majority - older, less educated, conservative and much less active people;
- Laggards – very conservative and the least educated people.

For an idea, that is based on an innovative or modern technology, to be sustainable, it is necessary to be aware of each adaptation group, understanding each group's motivation.

Initially, the basis of accepting innovations is the influence of mass media, but as the user network grows, the impact of other users becomes increasingly relevant (Robinson 2009).

Diffusion of innovation in different groups of users can be simulated using array functionality, which creates opportunities to consolidate decision-making processes into hidden structures, offering opportunities to build models that:

- Describe complex structures;
- Allow the user to experiment with variable data.

The basic principles of diffusion are similar in all groups - the number of users and the adoption rate (coefficients are different for each group) determines the increase of users in each group, while the predicted rate of use and the growing impact of competitors during development determines transition to other technologies (see Figure 3).

The model allows simulation experiments indicating user group distribution and individual characteristics of each group – acceptance rate and the expected duration of use. As a result, potential user dynamics can be analyzed in groups (see Figure 4) or for the technology in general (see Figure 5).

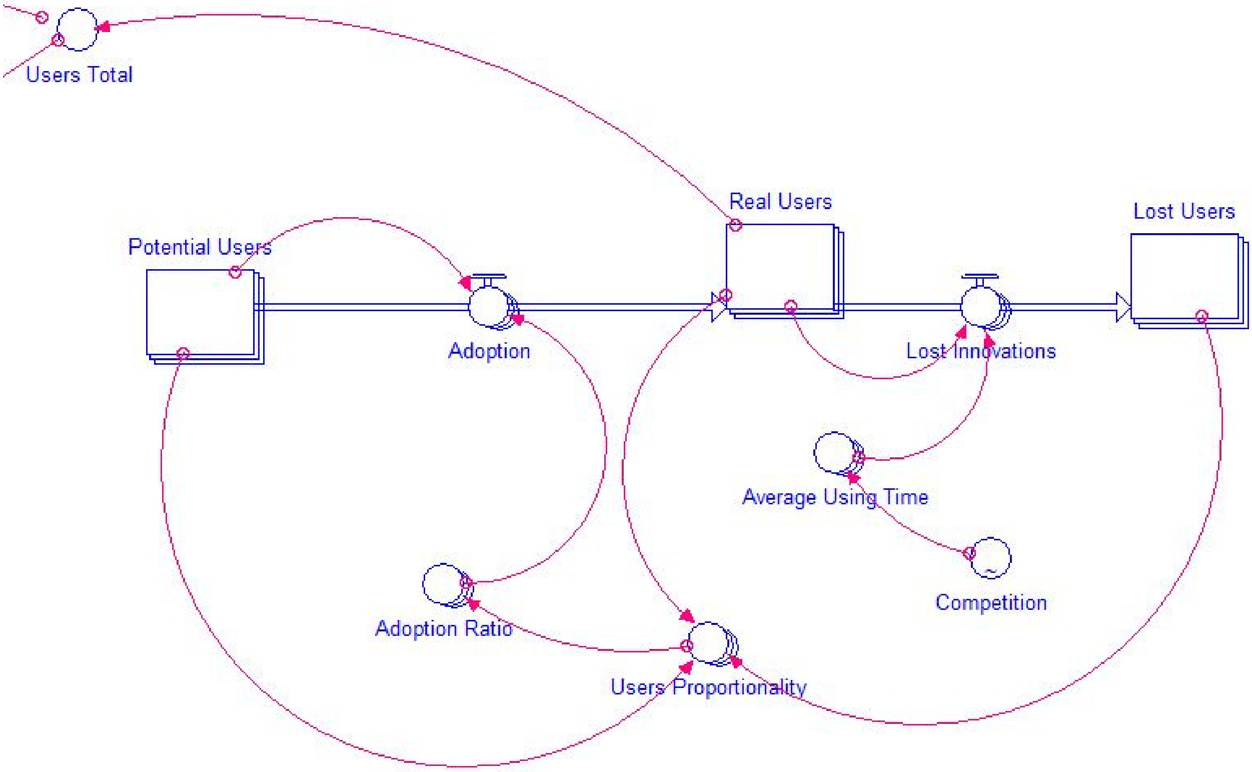

Figure 3: Users acceptance model.

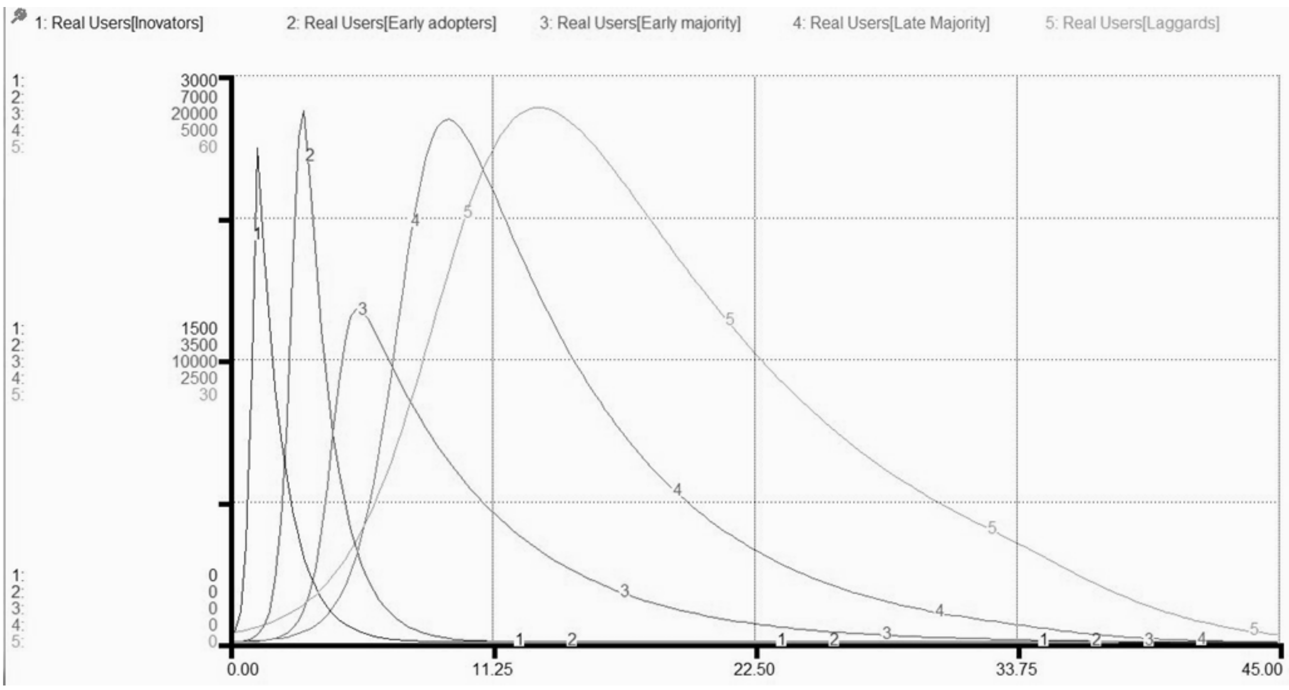

Figure 4: Users distribution changes among groups.

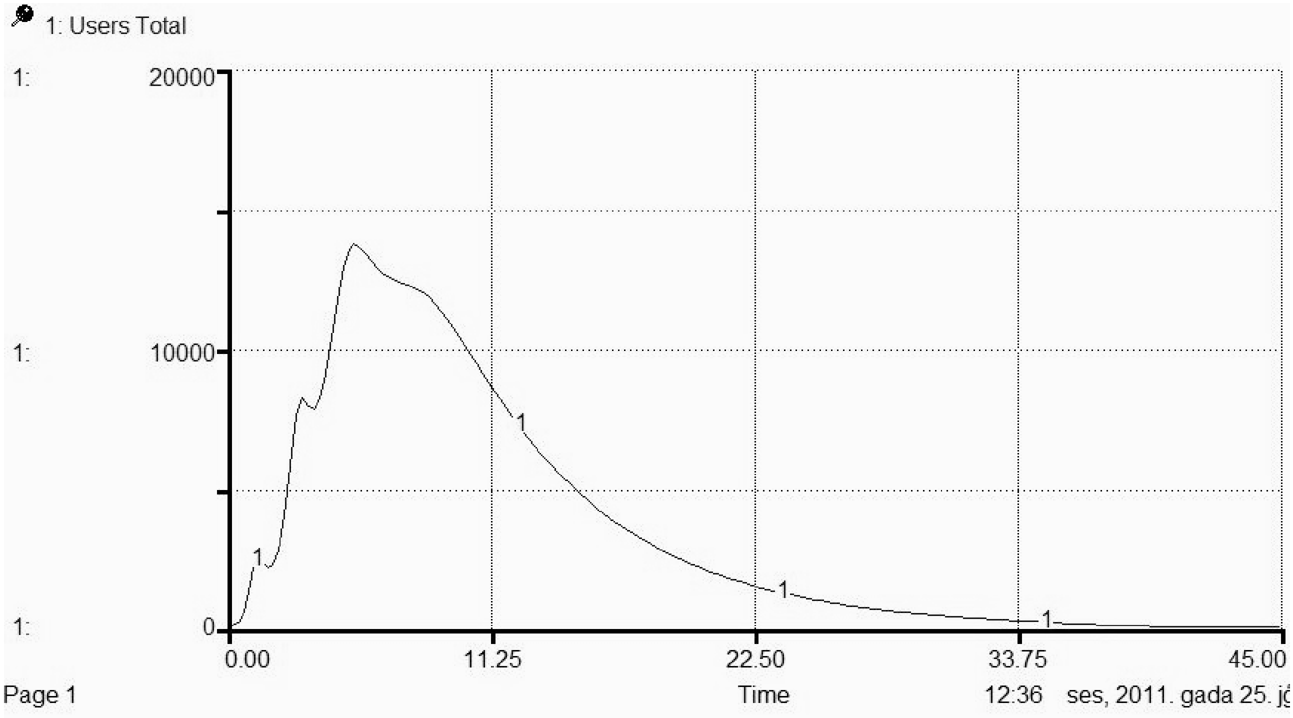

Figure 5: Total use distribution.

The model can also be used to analyze the development and life-cycle of the technology when expanding applications, creating new products or entering new markets.

Task Technology Fit (TTF) model

Goodhue created the Task Technology Fit (TTF) model, which bases the intention to use technology and the effective use of technology on the fact that the capabilities of the technology match the tasks that the user must perform. Technology assessment is based only on the extent to which it is applicable to solving or performing specific tasks (Goodhue et.al. 1995). Tasks (possible applications) describe all tasks that a user can perform using technology. Technology describes the available options a user has to perform a task.

Cane appended TTF by adding characteristics to describe individuals, emphasizing that different people may use different technologies to perform a task. Individuals are characterized by their skills to use technology, experience and their motivation to use it (Cane et.al. 2009). Compliance with "technology - task - individual" is a prerequisite for the real use of technology (see Figure 6).

Goodhue identified eight factors that influence task-technology fit, but in 1998 these were clarified and expanded to twelve. Dishaw (Dishaw, 1998) combined TTF factors into four main groups:

- Internal compliance – the ability of the technology to provide qualitative, precise and reliable data;
- Representation compliance - data compatibility, technology, the transfer of applications and services between different environments and equipment;

- Contextual (content) compliance – timely access to important (essential for the task) data and functions, an appropriate level of detail and functionality;
- Accessibility compliance - available in real time, everywhere, but the user interface is designed to be intuitive enough to not require separate training (assuming that there is experience with similar technologies). Instead of user support - user's ability to manage and choose the functionality required, create applications and extra features. Data and privacy protection is provided.

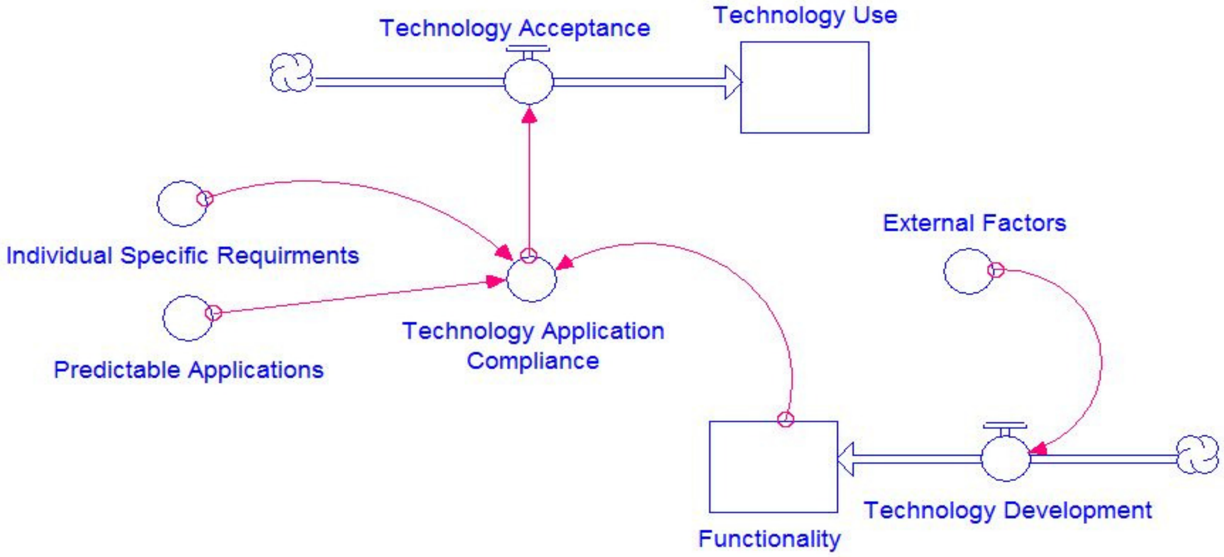

Figure 6: TTF structure in Stella environment.

TTF does not include user attitude, user opinions and views on technology or social impact, which is its biggest drawback (Yen et al, 2010). Yen put forward the idea that the technological compliance dictated by TTF is at the basis of the creation of subjective views and perceptions, but these views are affected by external factors that are not directly linked to technology. However, researching technology use in organizations shows that the compliance of technology directly affects intention and actual usage.

The main advantage – the aim of TTF is to determine the application compliance of a specific technology. It is believed that TTF is sufficiently suitable to perform the assessment of information processing systems (Cane 2009). By assessing the possibilities to include TTF factors in a simulation model, it was concluded that the model allows assessment of two most widely-known technology innovation development directions. In the case of demand-driven development, technology makers must be able to determine what kind of tasks users want (are ready, plan, imagine) to perform and design technology functionality accordingly. In the case of technology pressure-driven development, a developer knows the technical possibilities of the technology, but users and developers are still unaware of all the possible technological applications in the near and distant future. As technology develops, users can make out new tasks and new fields of application, which current potential technology users (and developers) cannot assess, because they do not know that it will be necessary. It is possible that the fields of application of the new technology will not correspond to the initial aim of its developers.

The more innovative the technology, the more difficult it is to control what applications may develop and how user habits may change during its development. Consequently, the model of a dynamic system must include the increase in user knowledge and experience over the course of technology development, and the impact of real use on the further development of the technology.

Technology acceptance model (TAM)

By studying factors that determine the attitude of an information technology user towards technology and its acceptance, Davis (Venkatesh, Morris and Davis et.al. 2003) developed the Technology Acceptance Model – TAM. TAM is widely used to assess technology acceptance in various fields. The model is based on the assumption that people will develop a positive attitude towards technology, if it is perceived as a useful and easy to use. This attitude will lead to the intention to use technology and therefore generate real use of this technology. Perceived usefulness is the users' belief that a particular technology will help to perform daily tasks more effectively. Technology is perceived as easy to use if potential users believe that its use will not result in extra effort (Yen et.al. 2010).

TAM is widely used in various technology acceptance studies for model validation for different technologies – mobile phone communications (Lopez-Nicolas et.al. 2008), mobile banking services (Zhou et.al. 2010), and for the research of additional factors that determine technology acceptance. TAM extensions include the following groups of studied factors:

- Social impact – by receiving information about a technologies usefulness and ease of use from acquaintances or other users, the potential user forms an opinion that for him this technology will also be useful and convenient (Lopez-Nicolas et.al. 2008). In the sustainability model of a technology social impact can be seen as the impact of common user experience and publicly available information on the potential ease of use and usefulness;
- User network size impact – a larger user network is considered an additional benefit, expecting, that it will ensure better service, user support and social recognition (Pontiggia et.al. 2010). Lab experiments of Pontiggia show results that users can make the decision to use technology with a larger number of users even if this technology is rejected by other parameters. In the developed model this result appears as a feedback loop from the number of users to the growth rate of the number of users.
- Technology parameters have been further studied by combining the technology acceptance model (TAM) and the task technology fit model (TTF), and by a detailed analysis of precise factors that have an impact on perceived usefulness and perceived ease of use. However, a user

primarily subjectively perceives and analyzes the specific technical indicators by comparing them to existing knowledge of the technology and the expected level of technological development;

- Freedom of choice – the opportunity to choose whether or not to use the technology. It is assumed that, if users have the freedom of choice, there is the possibility to reject and do not use the technology, or use it partially.

By summarizing the factors and additions included in TAM and TTF, as well as technology development to a certain level of development, the user acceptance model structure in Stella notation can be seen as it is depicted in Figure 7.

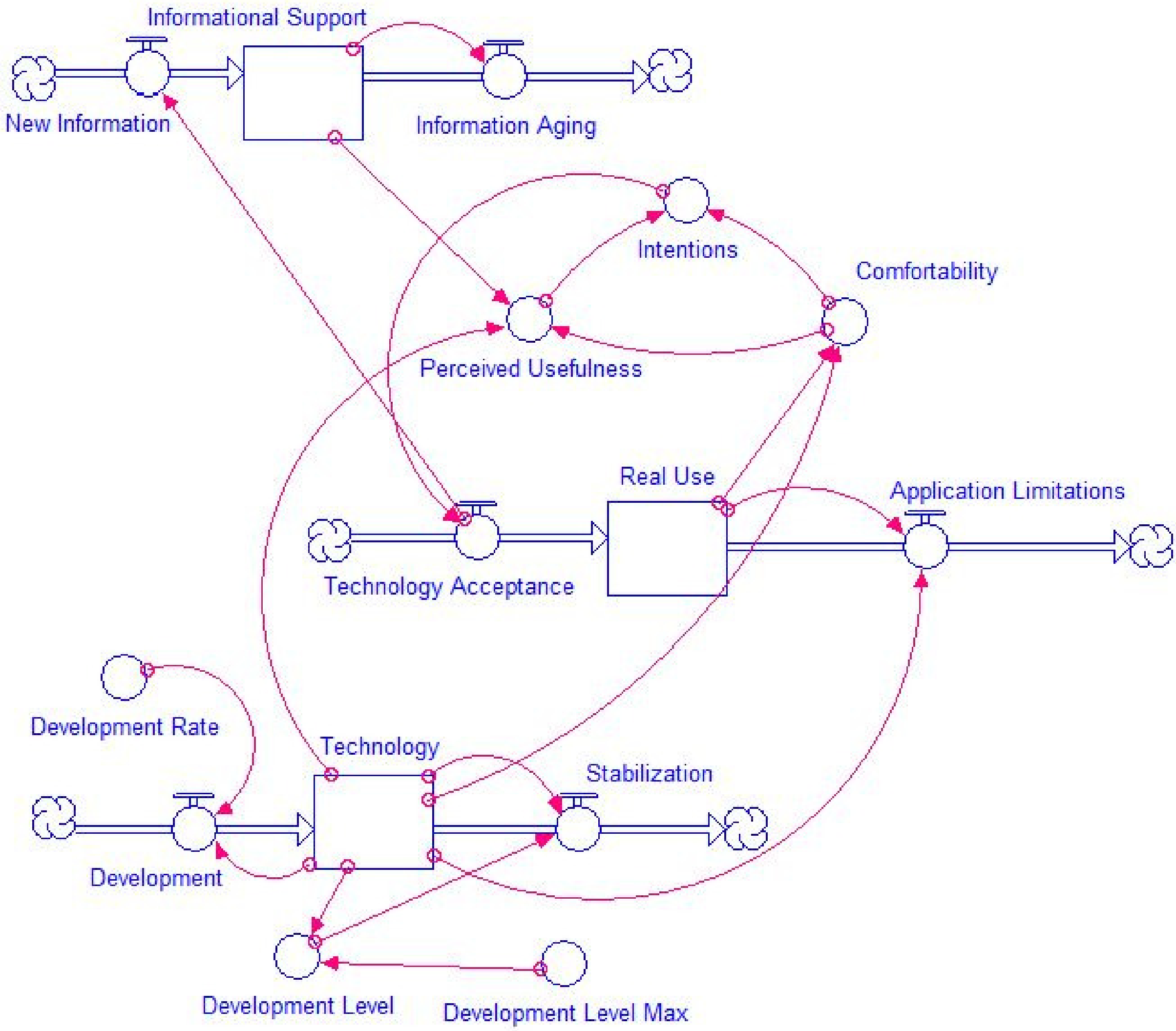

Figure 7: TAM and TTF structures in Stella notation.

The real reason for technology acceptance is intent, the formation of which is affected by:

- Information about technology (depends on the spread and development speed of the technology);
- Development level of the technology;
- The current level of technology use.

Curves that correspond to the theoretical technology acceptance process can be obtained by experimenting with the model (see Figure 8).

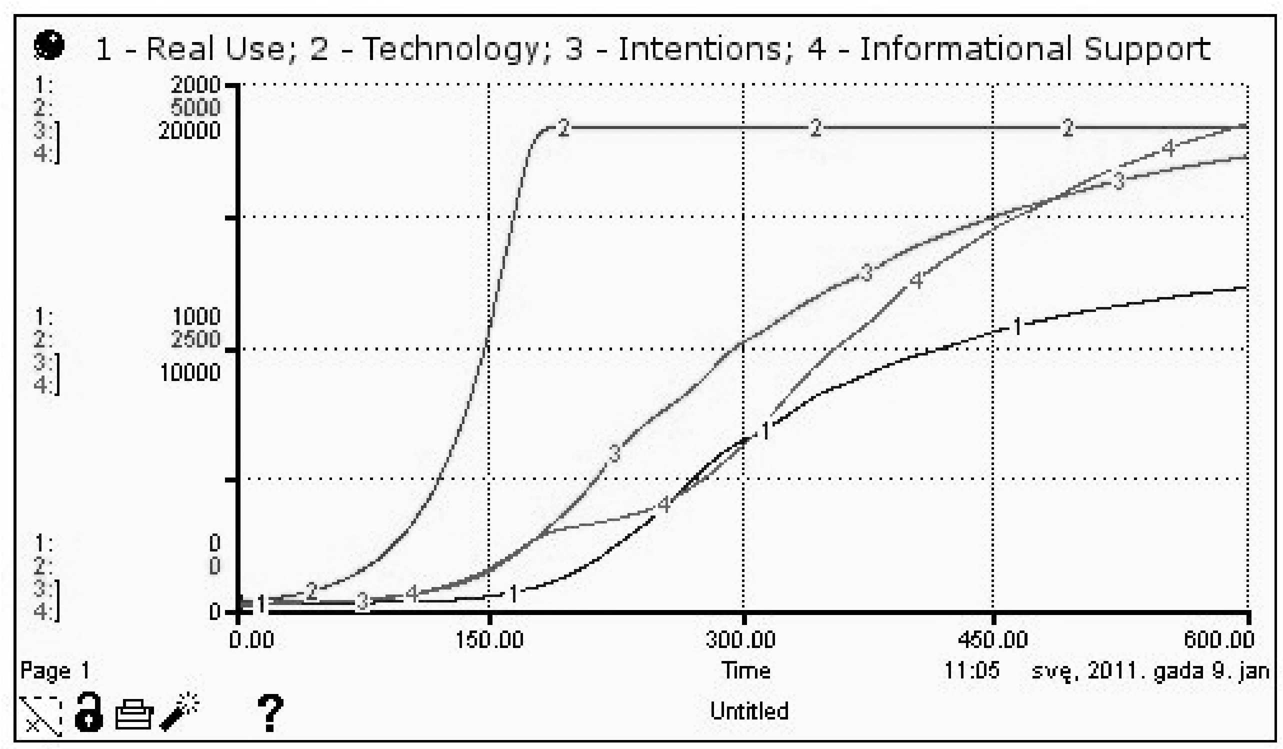

Figure 8: Results of technologies real use.

The result of the simulation (see Figure 8) shows that the availability of information about a technology increases as the technology is being developed, after that – when the technology gains user recognition. The intention to use the technology is followed by real use.

Unified Theory of Acceptance and Use of Technology (UTAUT)

Integrating researched elements of eight different models Venkatesh, Morris, Davis and Davis (2003) formulated the Unified Theory of Acceptance and Use of Technology (UTAUT). UTAUT sets four main factors that influence technology acceptance and use - performance expectancy, effort expectancy, social influence and facilitating conditions, and four related parameters – gender, age, experience and voluntariness (Venkatesh et.al.2003).

The interaction of factors and related parameters leads to behavioral intention, which usually is the basis for use behavior. Performance expectancy is defined as a persons' belief that the use of a system will help raise the efficiency of the task. It consists of five elements:

- Perceived usefulness – the degree to which it is believed that a particular technology will help to perform daily duties;
- Extrinsic motivation – external environmental factors that motivate the use of technology;
- Job-fit – the technologies proposed solution compliance with the tasks;
- Relative advantage – the advantages of the technology over its predecessors or competitors;
- Outcome expectations – the product / service obtained as a result of the use of technology or the self-evaluation of one's activities.

Effort expectancy is defined as the convenience of using technology while respecting the perceived ease of use and the subjective assessment of the complexity of learning, and using the technology.

Social influence shows the user's impressions about other important people's opinions; whether they believe that the user should use the new technology.

Facilitating conditions are defined as a user's opinion about to which extent a technical and organizational infrastructure, that is necessary for the use and receiving of support for the system, is working and available. If performance and effort expectancy is positively evaluated by the user, facilitating conditions cannot significantly affect the intention to use technology, however, together with age and experience they are essential to the real use of technology.

UTAUT is criticized for having too less impact set aside for the technologies compliance with tasks.

By evaluating the possibilities of using UTAUT for the sustainability assessment of a technology, potential constraints can be identified:

- The intent to use is measured without further analyzing the implementation of the intent;
- The model is static; it does not analyze processes and does not provide changes to previously fixed parameters.

At any given time a potential user's decision on the use of technology is based on the perceived, subjective assessment of technology. But users' opinions about technology and the factors, that affect technology acceptance, change during the development of technology. User opinions are affected not only by the changes in the studied technology and the increasing publicity and market share, but also competing and complementary technologies, as well as external factors, such as the economic crisis and financial position changes.
UTAUT is based on the fact that it is assessed by how a user perceives the system, i.e. the users' intention is viewed through the prism of a potential user. But if the technology is not yet developed, the users' opinion is comprised of public reviews and technology assessments.

UTAUT is one of the main original data sources for the Integrated Acceptance and Sustainability Assessment Model (IASAM) (Barkane, Ginters et.al 2010).

INTEGRATED ACCEPTANCE AND SUSTAINABILITY ASSESSMENT MODEL (IASAM) CONCEPTION

The conceptual structure of the Integrated Acceptance and Sustainability Assessment

Model (IASAM) pilot model consists of four layers that describe the activities involved in the structure and processes of technology development, and the accumulation of resources and factors, which are vital for technology development (see Figure 9):

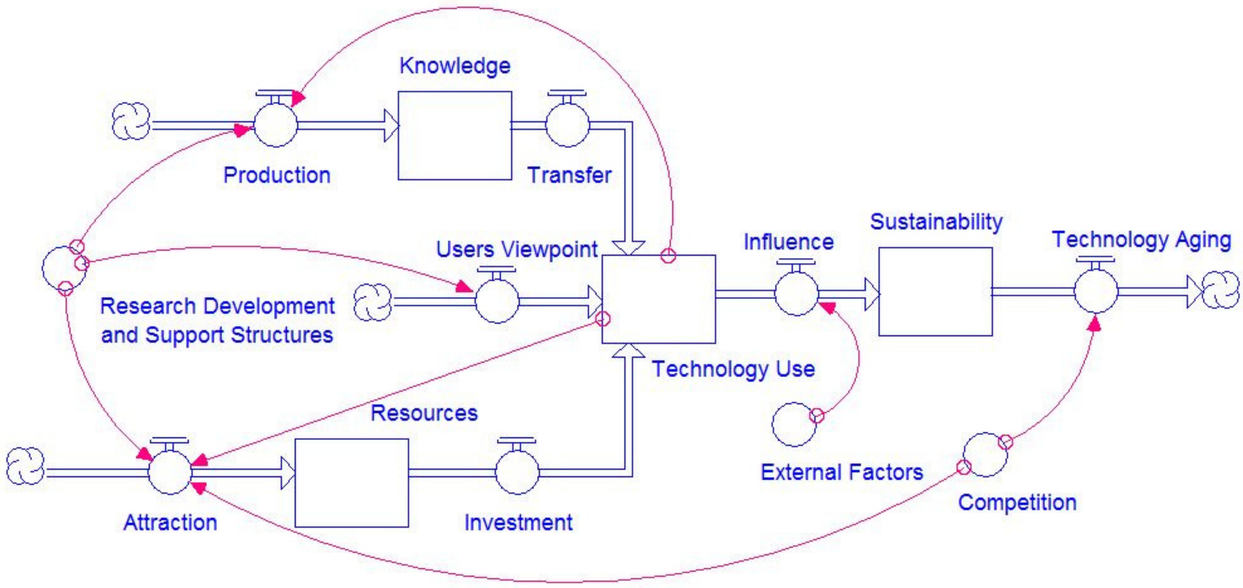

Figure 9: Conceptual IASAM pilot model structure in Stella notation.

- The creation and transfer of knowledge as a result of business activities;
- Research development progress and support structures;
- Mobilization of financial resources;
- The formation of market structures.

The starting conditions for the IASAM model are formed by the assessment results achieved during the technology acceptance process. These are based on UTAUT methods.

When using system dynamics in the assessment of technology sustainability, it is necessary to define system boundaries and determine factors and impacts, which will be included in the model. National or regional innovation systems, structural innovation systems and technological innovation systems are being researched in innovation system studies. If two or more systems or technologies affect each other, they can no longer be simulated as independent. By researching national or regional innovation systems, they are being confined by space. Structural innovation systems are limited by a certain industry. Technological innovation systems are not restricted by national or industry boundaries. Studies of such systems are limited by the knowledge base used or the potential scope of use (Bergek et.al. 2008). In the process of technology development, different technologies and fields of knowledge overlap and the potential scope of use changes over time, therefore accurate system boundaries are defined by the objective of the study. However, all factors, that determine technology creation, diffusion and use, have to be respected. The Integrated Acceptance and Sustainability Assessment Model (IASAM) is built based on the technological innovation system concept, without emphasizing the national or regional boundaries.

The IASAM model is intended to assess technology sustainability starting from development. The model respects the growth of user knowledge during the technology development process. Knowledge and experience increase simultaneously with usefulness of the technology.

Technological development, especially in the technological solution replacement stage, is not an even process. There are various "critical points" in system development where positive external factors are necessary for further development.

The technological change model (Geels 2007) defines that it is not always possible to determine which technology will stabilize, and how. Similarly, technological developments can also be affected by the overall economic environment, by determining opportunities to attract resources or meet demand. Viability of any technology depends on the financial capability of investors and users, which provide better recreation opportunities and advantages in the fight with competing solutions.

IASAM FACTOR GROUP CHARACTERISTICS

External (environmental) parameters

External parameters – factors that affect the process of technological innovation and technology development, but on which technology development has a minor (insubstantial) effect. They describe the environment in which the system operates. Although the innovation system or new technology cannot affect external parameters in short term, changes in the environment, for example, economic crisis or rapid changes in raw material prices, affect the whole innovation system. System boundaries, that precisely define the environment in which the system operates and variable factors, are necessary to define external factors.

There are two approaches to assess technological innovation systems:

- National political or environmental features do not have an impact on whether the technology will develop. Local factors have an effect on where the technology will have favorable opportunities to develop, and when and where it will have the chance to enter a rapid growth phase. If the idea of the technology is sustainable, it will develop in another country / region or when there is a change in external factors;
- On the other hand, if the technology is evolving in another environment, it consists of other innovation system actors, other users are involved in its assessment, and so the technical parameters of the technology and the market structure are formed differently, effectively making it a different technology.

Since the aim is to explore a specific technology whose development has already begun in certain external economic and social conditions, the model respects external environmental conditions. One of the possible simulation scenarios is the ability to simulate changes in external factors and their impact on technology development, thereby assessing the impact of factors on a specific innovation system and evaluating the stability of the newly formed system, which is affected by changing external factors (for example, economic crisis). Based on theoretical studies, the model should include the following external parameters:

- Overall economic activity – a complex parameter, the weighted average GDP of countries participating in technological development. Overall economic activity should be evaluated for an average period of time (5 to 10 years) to determine which business cycle phase is currently dominant in the economy;

- Economic optimism – derived from statistical surveys (the cumulative index for business, consumer and bank optimism), shows consumer and investor forecasts for near-term economic development;
- Access to funding – the interbank interest rate can be used as a funding availability / price index;
- Level of education – describes the average level of education in the for technology development potentially usable environment (country, region);
- Employment – percentage of the able-bodied, describes the possibility to attract workforce. This parameter should be included in technology assessment, if it is necessary to change the number of employees. Employment must be assessed as a possibility to attract workforce and as the “consequence” of technology – the formation of unemployment;
- Total score of the industry - the economic growth rate of the industry, which develops the new technology. For technologies, which develop on intersections between sectors, a combined parameter of the industries involved can be used.

Competition must be distinguished as a separate external factor – technologies that are already in use (existing technologies) and technologies that are currently developed or will be in the future.

Creation and transfer of knowledge as a result of business activity

The function of knowledge creation describes the formation of a basis of knowledge and ideas, their formulation and distribution. Various types of knowledge can be examined - scientific, technological, manufacturing, market, logistics and design expertise (Suurs 2009). The function of knowledge will vary depending on the level of technological development.

While forming potential applications, the emergence of new ideas and potential use is determined by the activity and interaction of the creative environment, active sharing of knowledge, borrowing and adaptation for other uses or by adding the experience from other technologies.

Processes, that ensure the formation and spread of knowledge, may include the following:

- The current knowledge base and administrative capacity of research structures determines how available financial resources will be attracted and transformed into knowledge creating activities while deepening the theoretical knowledge and creating a technological knowledge base;
- Knowledge diffusion in conferences, publications and media creates a vision and

notion of technology development opportunities:

    - By shaping future demand from users (creating market demand),
    - By attracting developers;

- Creation of new products - the link between research and production. Joint projects form a production and process knowledge base, which facilitates decision making on investments in technology and production development, allows to experiment with the creation of new market structures and to create market demand;
- The possibility of simulation encourages new entrepreneurs to take part in innovation. That increases the competitiveness of existing technologies and the ability to raise additional resources:
    - Internal competition ensures further development of knowledge,
    - Too many developers cause the fragmentation of available resources thereby promoting a new process – the consolidation of developers.
- The number of people (number of students and researchers) promotes technology development and prepares a user base.

Innovation can occur as a result of two different forces. It can be a user-led and demand-driven, and, as a result, the created product or service meets the users' expectations. Solutions, which are based solely on the current user experience and current tasks or activities, ensure the further development of technology. The basis of new, substantial and disruptive technological leaps is solutions, which are based on vision and new technological possibilities – development driven by pushing technology.

The sustainability assessment of such technologies is significantly more complex. When developing a technology that is driven by user demand, it is known that a market for the technology already exists. When creating a technology, where potential users may not yet be aware of the necessity of its offered possibilities, users are only part of the factors that ensure development.

The role of business in technology innovation is to turn knowledge into business opportunities and create products or services that use the available research expertise. The new technology enters the market as experimental projects - niche products, partial integration of technologies into existing products. The main tasks of business activities – find the usefulness of the technology in practical solutions, ensure economic viability, create market structures and promote the emergence of innovation-friendly laws.

At the beginning of technology development entrepreneurs face risks, because it is not possible to determine all complex effects, which could contribute to or hinder the commercialization of technology. In case of significant technological changes, it is necessary to coordinate the new technology with existing structures (market, technological, legal), or to make changes to these structures, as well as to ensure the support of potential users.

Entrepreneurs contribute to the applications of technology, ranging from the first niche products to consumer goods, and accumulate knowledge of technology use. Promoting investments in development, investment projects, creation of new businesses or diversification of existing business operations, one of the affecting factors is the expected profit of the industry, which is determined by the expected market size and demand, technology development vision, as well as by the accrued, but not yet realized, level of knowledge.

By combining the knowledge formation and diffusion modules with the role of business in developing new products, a model structure (see Figure 10) is proposed, which describes the creation of new products where technology push and demand pull operate simultaneously.

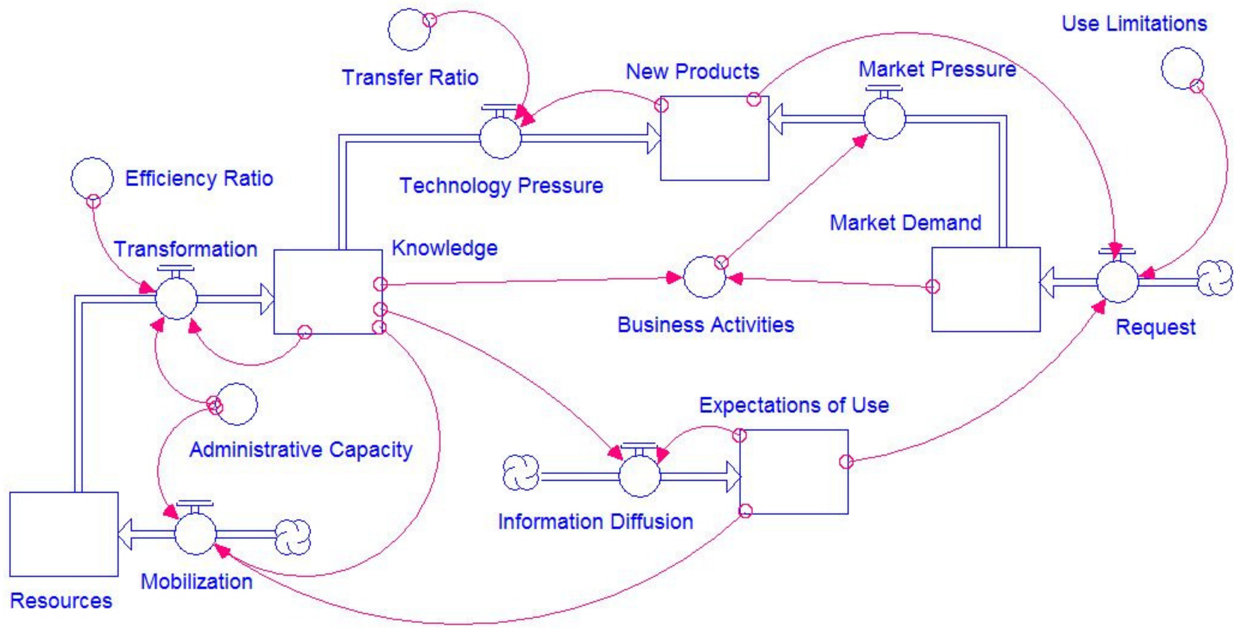

Figure 10: Knowledge and market demands activated new products development.

The model includes a process, which determines that market demand forms when a vision of use initially develops. This is influenced by the formation of knowledge and diffusion (see Figure 10).

The results of experiments are depicted in Figure 11 and show the influence of the two leading forces.

A process is simulated where, initially, new products develop when the accumulated knowledge reaches a certain level, and invoke separate activity peaks.
But when the technology spreads and information reaches users, a demand-driven process begins, where the development of new products is driven by business and growing demand.

Research development progress and support structures

The function of research development progress describes how development is promoted and supported in a specific technology, sector, field or area of use.

Technology standards define the possibilities of technology development or, if strict supporting standards are already in place, limit the possible development of the new technology. The existence and compatibility of technology standards with a new technology is determined by a normative basis - state / national union rules, requirements for specific technological parameters. Technology development influences standards through possible applications and support structures by comparing current technology development trends with the best (sustainable) technology

vision.

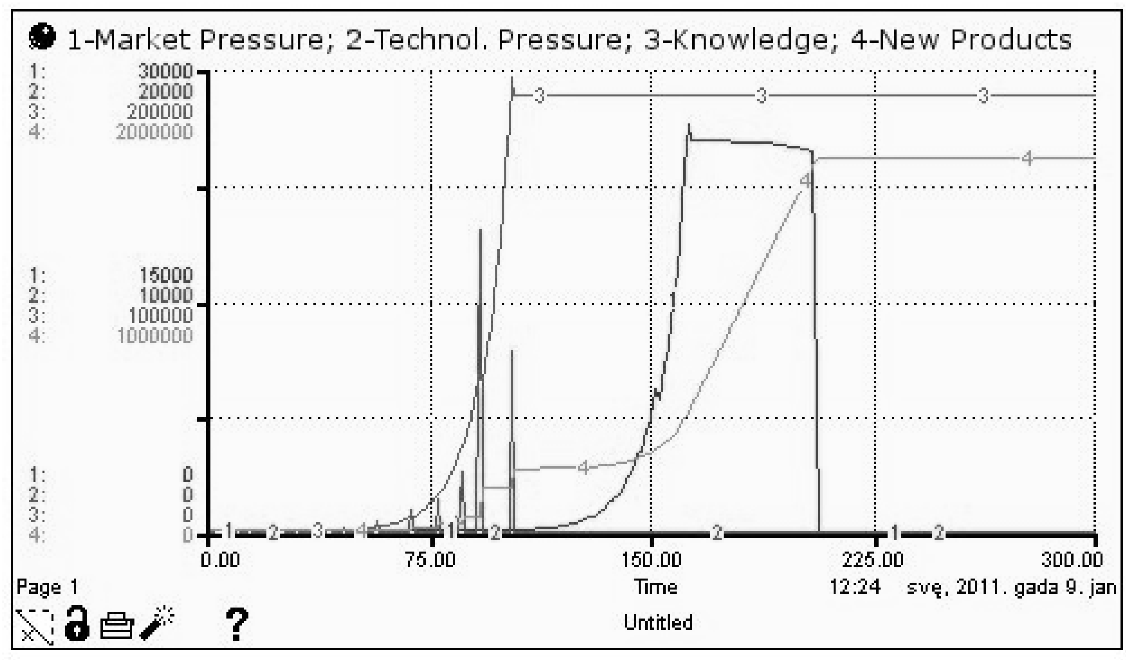

Figure 11: Technologies and request activated new products development trends.

Research development progress also affects the effectiveness of fundraising, either directly by grant rules, or by developing laws (customs, taxes for specific technologies) or strategies, that contribute to certain directions of development.

Social opinion is formed by visions and publications, which set a level of requirements the new technology has to achieve, and show new technological possibilities, thereby forming the opinion of users (and funders) about areas of application and desired functionality.

Support structures develop as technological support forums and support organizations, as a possibility to get advice (for a fee or for free), as organizations that promote and summarize public opinion, as well as political lobbies for the new technology.

The IASAM model includes support structure development for the new technology. Supporting changes in legislation and standards, which are favorable for the new technology, has an impact on investment decisions, development trends, and it develops the use vision for the new technology.

By combining the research development and progress, as well as the support structure modules, it is possible to simulate one of the variations of the research promotion and resource acquisition process (see Figure 12).

Analysis of the simulation results (see Figure 13) for the proposed structure shows, that both, possible vision of application and standard compliance, curves describe theoretical processes. It can be seen that the formation of support structures is more intense before the maximum level of compliance to vision and standards has been reached. However, the resource availability and technology development exponential curve shows that this structure does not contain vital development balancing factors. It is therefore necessary to include more specific resource mobilization and control factors.

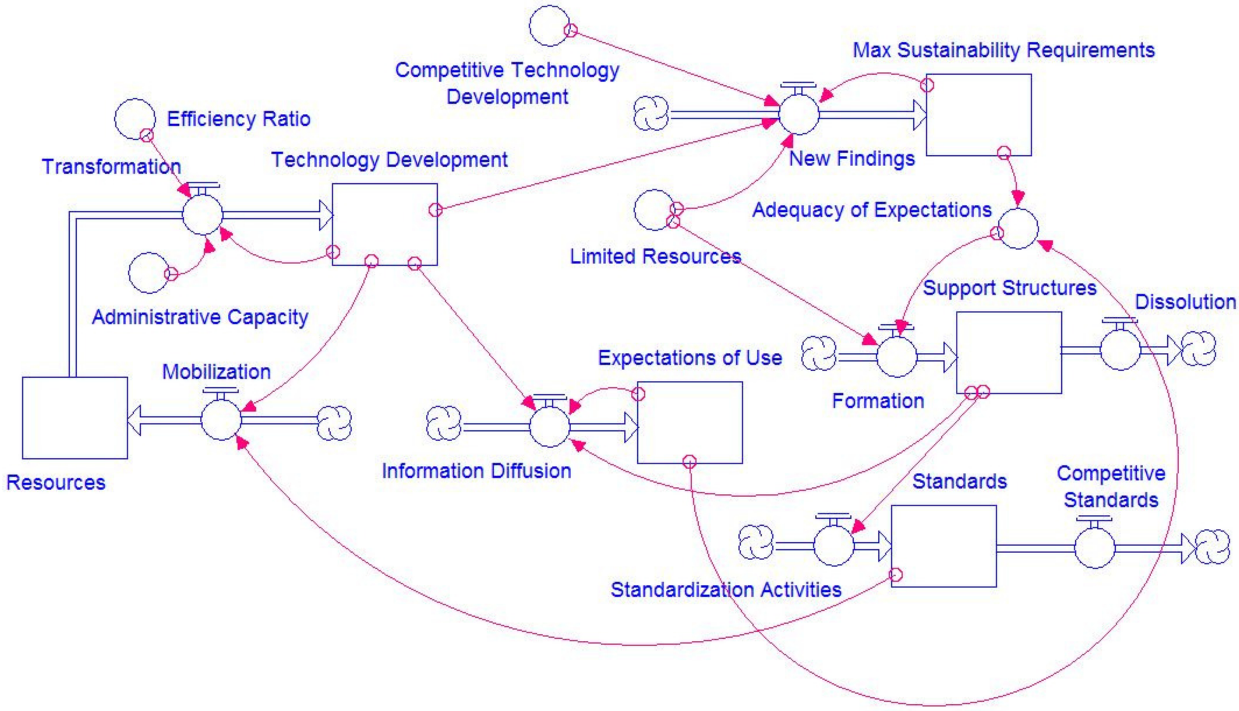

Figure 12: The support structures influence model.

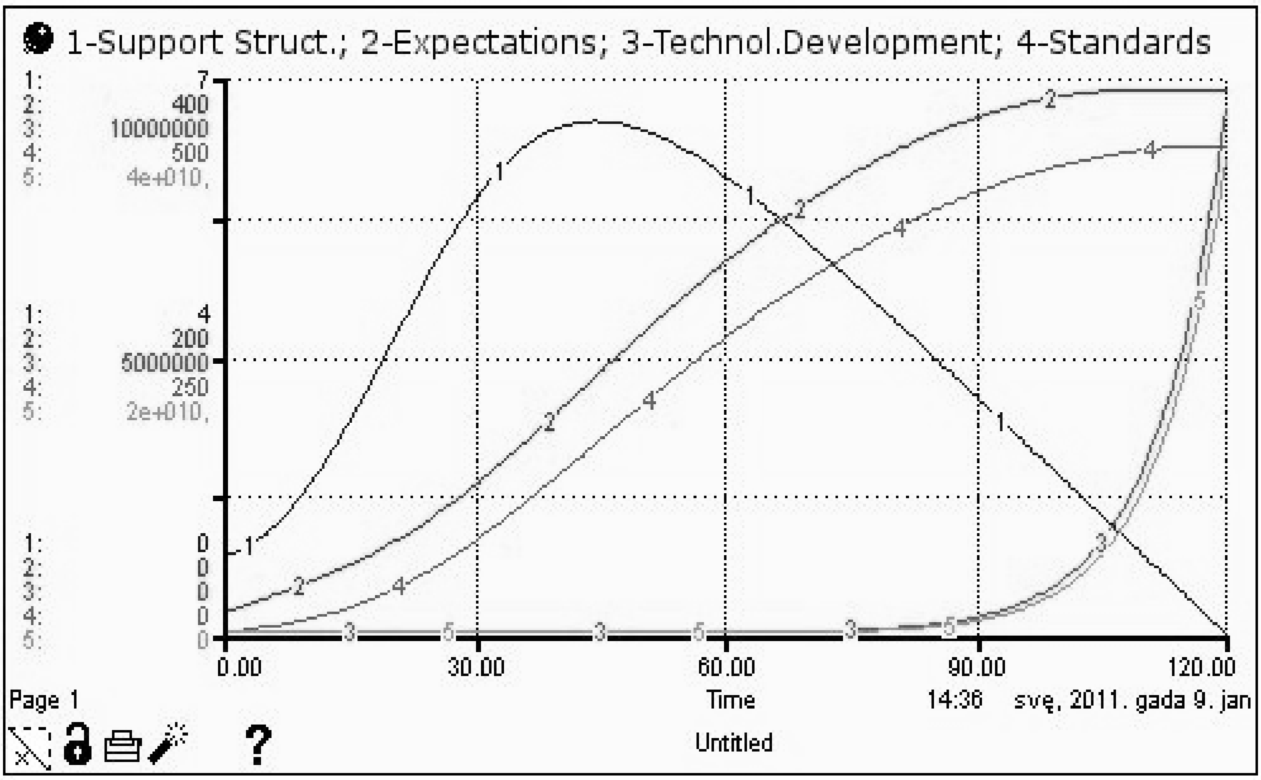

Figure 13: The support structures simulation results.

Resource mobilization

Resource mobilization includes availability to funding (investments, credits), profit distribution, the ability to attract human resources for development and dissemination, as well as attract additional investors, based on the technology vision, the idea or profit figures. Mobilized resource utilization can be viewed in three directions:

- Technology (also consumer goods) development;
- Creation of a knowledge base;
- Formation of market structures (including marketing, PR etc.).

Resource availability is influenced by external factors. Resource distribution depends on the current level of knowledge, technology and market development, but all three directions operate simultaneously at varying intensities.

To provide sustainability, the resource acquisition module needs a balancing loop, which ensures the balancing of increases in resource availability. A high investment inflow is associated with risks that the investments will not be used effectively enough. Disappearance of competition for resources results in a technology boom and, if by that time the curvature change point (approaching the limit of technology development, ending exponential growth) of the technology development curve has already been reached, this may end with the collapse of the technological system or company.

If technology investments are not used effectively (this can be measured by determining the number of usable prototypes, the user network growth rate, the expansion of use areas) and developers cannot provide new applications, or there is no cash flow from users, bankrupt businesses emerge. Investors start to assess the technology as risky and allocate resources more cautiously. A similar result can also be caused by external factors (financial crisis) when the increase in interest rates limits available resources.

In this particular IASAM module (see Figure 14) resource acquisition is balanced by the technology development reserve.

It is assumed that the maximal limit of technology development is known and resource acquisition is adjusted according to development opportunities. Resource acquisition speed depends on the technological development reserves and resources already available. The rate of technology development is affected by resource availability and the current level of development. Two peaks can be observed for the information about technology – before intense development of the technology (the time when resource acquisition is happening at the most rapid rate) and during the rapid growth of technology users (see Figure 15).

Formation of market structures

Technology development does not happen in an isolated environment. Planned (or potential) applications already have a solution (existing technology) and, possibly, different technologies are being developed simultaneously. Potential consumers and investors make their decisions by comparing technologies, which compete in the same market. Simulation offers the opportunity to assess and compare the parameters of competing technologies.

However, users rarely analyze all available alternatives, because this type of process is immensely time consuming and complicated. The opportunity to further technology development and use is affected by comparable parameters. Factors important to the user - perceived ease of use, perceived usefulness, relevance to the task, technical (relatively) specification, known from TTF and UTAUT. Tasks (possible applications) change during technology development. User opinions change on what will be necessary.

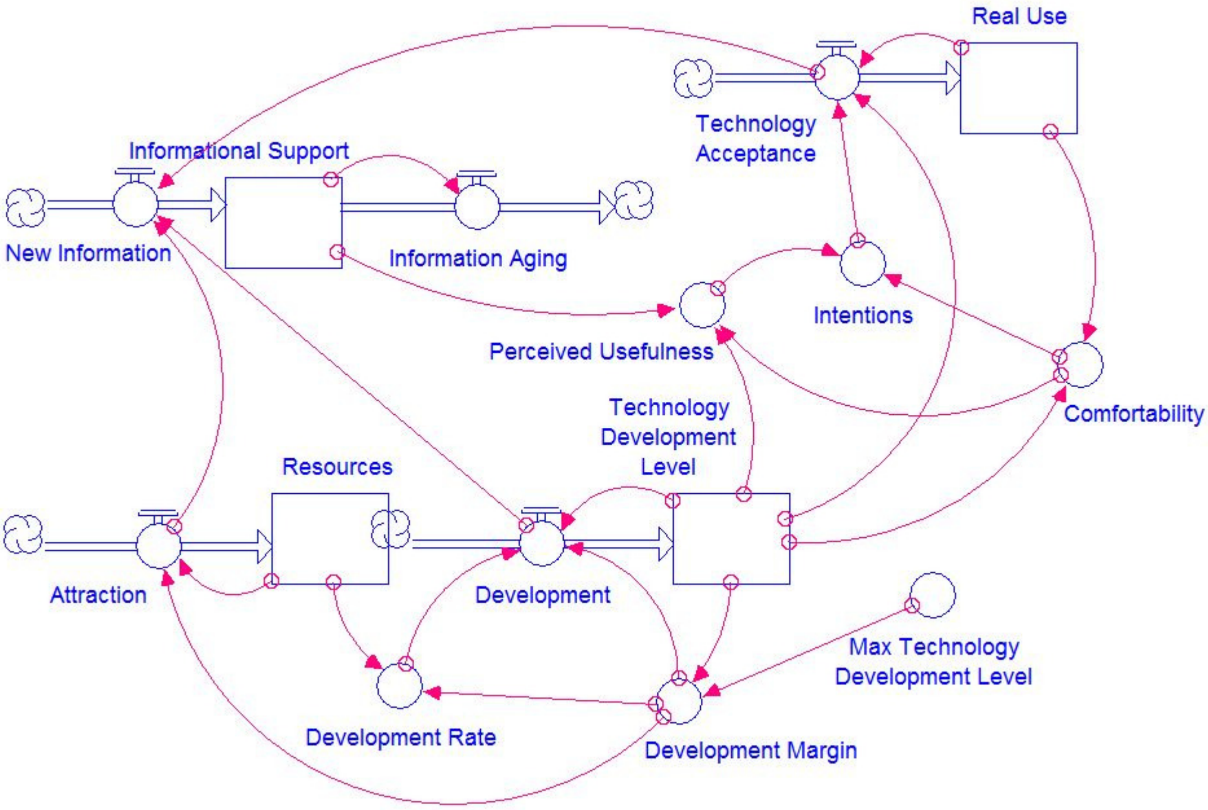

Figure 14: The resources attachment, technology development, and information dissemination and users amount changes cycle.

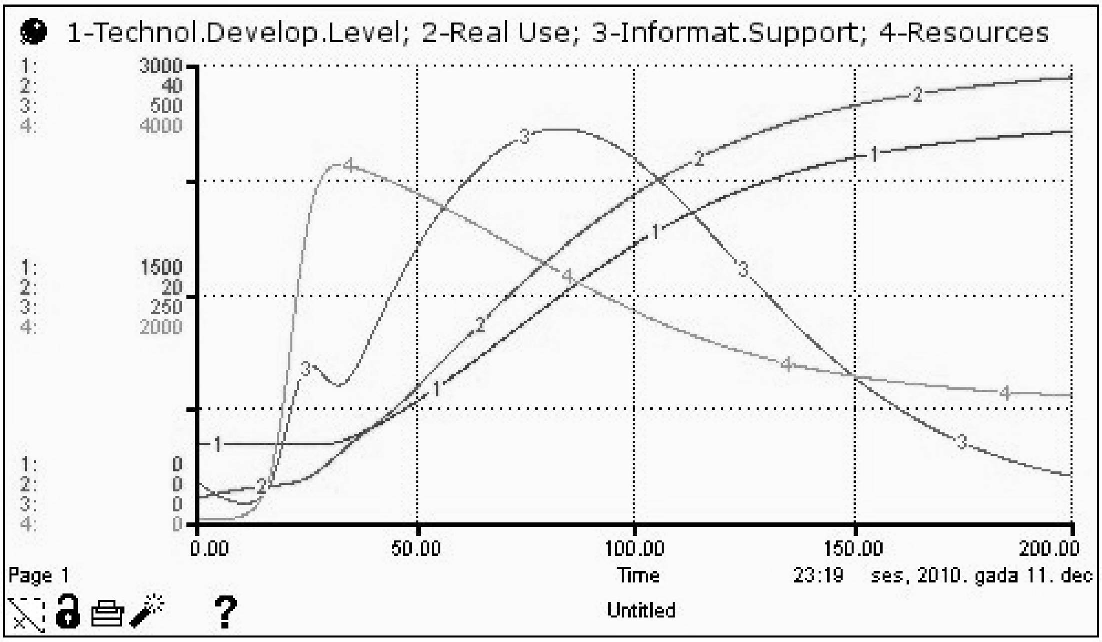

Figure 15: The resources attachment simulation results.

One of the factors of user rating is the potential total financial result – the cost of switching from the currently used technology to a new one, and compatibility (data and software transfer, the possibility of using existing equipment, etc).

Social factors, such as the modernity of technology, (social impact from the UTAUT conception), advertising and the amount of information on existing technologies, (publications) form a users' opinion by changing the intention of use.

User rating determines the changes in user numbers (market unit) and key technology developments:

- Functionality – the development of additional functions and new possibilities of use;
- Efficiency - ease of use, speed, ease;
- The need to provide users (existing and potential) with knowledge about the possibilities and opportunities to use (study) the technology.

Users rate technology based on their own experience, vision and social impact. The actual number of applications and area diversity characterizes technology viability and sustainability. The key business indicator – the potential value of the technology life cycle can be determined by assessing the real applications of the technology and users' willingness to pay. The market is defined not only as a place for transactions (buy and sell), but as an environment and area of application where the new technology is used.

The current value of technology is determined not only by the number of users, but also by the level of usability. The "visibility" of technology use in the public space, the general opinion that specific products are "modern", "cool" or "prestigious", together with technology assessment, promotes the further spread of technology.

Funding from the resource mobilization unit is vital to form market structures, which provide technology access to users.

CONCLUSIONS

Only a technology, that can balance the financial goals of developers with environment sustainability, can be financially successful in the long run. Even if the technology has no direct impact on the environment, the environment changes during the process of its use, and the technology sustainability assessment is directly linked to its impact on the environment, economy and social processes.

If the aim of new technology development is long-term sustainability, it must be able to gain user recognition and become a part of social processes in organizations and the public. Consequently, technological development cannot be regarded as a purely technical process. The boundaries between internal (affected by technology developers) and external environments change during the development process of the technology. Technology joins into the environment, and changes consumption and production patterns.

User opinions about technology form before the technology has been tried out. The availability of information about the technology has a vital role in the formation of opinions. All characterizing factors of technology are not equally important to a users' assessment. The most important, to make a decision, are ease of use, usefulness, relevance to the task and, of course, cost.

Technological development may require changes in social and business structures and processes, and these changes are not always directly controlled by technology developers. Favorable external factors, which ensure the weakening of the existing technology regime, are necessary in order to achieve technological development.

Technological development can stimulate economic activity and GDP growth. GDP growth is associated with easier access to financing, which has a positive impact on technology development.

For a technology to enter the mass market, certain standardization is required. As manufacturing systems become more flexible, technology development is threatened by standardizing the product before the technology has developed close to its maximum financially justifiable level. By creating inflexible innovation or manufacturing processes, the opportunity to produce more and cheaper is achieved, but this limits the further development of the product, thereby risking, that it will be pushed out of the market by a competing, more innovative solution. Technology, which ceases to develop, is replaced by competitors, which are better able to adapt to changing requirements.

The main task of IASAM is to provide a potential audience with of more convenient and efficient simulation environment, which, as a result of interactive and immediate simulation, can accurately and in real-time predict the sustainability of the existing or new technology, or introduced changes. The currently existing pilot concept of the model intends the formation of four base layers by performing simulation activities with a predefined level of abstraction in system dynamics simulation environment STELLA.

The following can be mentioned as potential directions of development for the IASAM model:

- Determination of factors that limit technology development. Various limiting factors exist in socio-economic systems - physical limits (agricultural land, size of a city and number of hours per day are physical limits), limits of consciousness (the amount of information that is used for decision-making is limited), financial limits (for example, credit card balance), as well as legal limits, for example, licensing rights. The inclusion of restrictive factors into the structure of the model (and into real systems) would provide avoidance of undue exponential growth forecasts. It is important to assess the limiting conditions of technical parameters, which can have an impact on technology usability (bandwidth of communication channels, specific software requirements, mobility of a technical solution vs. performance, visualization possibilities vs. power consumption etc.);
- The choosing of certain significant factors within defined factor groups by attaching the model to a certain technology and making it correspond to the real situation. Data collection and analysis of a specific technology development study. However, there is the possibility of an opposite direction, which is aimed at the generalization of the model, and universalism. This would allow an initial rough assessment without investments, that

would be timely when using the IASAM model to assess specific technologies;

- Verification and validation to verify the functional and structural integrity of the model, and its completeness and compliance with the analyzed system. The repetition of historical data cannot be the main confidence rating of the model, because historical data represents how the system works in a particular structure or in a specific combination of factors, and it is possible that such a model does not represent all factors or the structure of a system. This can have an impact on the present and future of the system (Radzicki 2009);
- Development of scenarios which are suitable for the aim (user). Simulation allows studying a system by changing one or more of its parameters. In real life decision results will appear after months or years. Simulation results can be obtained in a relatively short time. A better understanding of processes, which ensure the functioning of a system, and knowledge, which allows making decisions based on more precise information about system mechanics and possible outcomes, is obtained by building simulation scenarios and analyzing the results;
- The development of a better human-machine interface (HMI) for the IASAM model and the preparation of recommendations to implement technology sustainability simulation.

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