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Trends and Scenarios of Key Information Society Factors and Technologies: Modelling Methodology and a Case Study

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Abstract: The main objective of this paper is to extract, formulate and analyse the general rules and principles that govern the evolution of key information technologies (IT), the information society (IS), as well as e and the economy using a holistic approach. In order to elaborate a model suitable for forecasts and recommendations we have defined eight to ten major elements of an IS that characterise its evolution in an adequate way, such as population and its demographics, legal system and IS policies, IT in use, etc. The evolution of the IS is then modelled as a discrete-continuous or discrete-event system, where the mutual impacts of each of the elements are represented within state-space models. Technological trends form inputs, while feedback loops allow us to model the influence of technological demand on IT, R&D, production, and supply. The technological characteristics of the IS evolution modelled in this way can provide clues to IT providers about future demand. They can also give R&D and educational institutions some idea on the most likely directions of development and demand for IT professionals. As an example, we will model the evolution of decision-support systems and their impact on technological progress, consumption patterns and social behaviour in Poland. The results presented here constitute a methodological input to an IS/IT foresight exercise carried out in Poland during the period 2010-2012 and financed by the ERDF.

Keywords: Information Society Technologies, Foresight, Quantitative Trend Analysis, Scenarios, Discrete-Event-Systems, Decision-Support-Systems

1. Introduction

The rapid technology-driven evolution of the information society (IS) has raised a number of research, technological, economical, political, and social challenges. The IS development laboratory that has enabled us discover new aspects of IS modelling was the EU accession of the twelve New Member States in 2004 and 2007. The accelerated implementation of EU policies concerning the IS in these countries, part of the Community's cohesion policy priority goals, has allowed us to make a number of methodological observations on the modelling, foresight and control of the development of the IS. This, in turn, has made it possible to draw more general conclusions regarding the evolution of the IS in Europe and its future scenarios. Some of these findings were first described in a series of reports prepared for the FISTERA (Foresight of the Information Society in the European Research Era) project – a thematic network of twenty organisations led by the Institute for Prospective Technological Studies (IPTS) – DG JRC in Seville.

New trends, processes, and phenomena concerning the current and future state of the IS have been observed, and several case studies (the EU New Member States and

Candidate Countries, Poland, Romania) can be referred to. The details of these findings are presented in the FISTERA reports . The main development achieved by FISTERA, compared to earlier theoretical work on IS models (cf. e.g. „,,) lies in the appropriate use of statistical data concerning IS indicators.

Other EU projects devoted to the investigation of the development of the Information Society that were financed within the 5th Framework Programme of the EU include SEAMATE (Socio-Economic Analysis and Macro-modelling of Adapting to information Technologies in Europe, more info on ist-world web page) and ISCOM . Both were concerned with the case of the EU-15 and therefore likely to become outdated following EU enlargement. A number of more specialised projects focussing on specific aspects of the IS have also been undertaken, among which is the FISTERA follow-up project "Techno-economic Foresight for the Information Society" (TEFIS,), which has been carried out at the DG JRC – IPTS over the last few years. However, the emergence of essential new methodological approaches was not the purpose of this project. Having studied the above research on IS modelling, it became necessary to elaborate new methodologies that can link different and differentiated aspects of the IS in a future-oriented evolution model.

To sum up, the results presented here can constitute a methodological input to any IS/IT foresight exercise. The paper does also describe an application of the above methods to elicit trends, and presents recommendations for the development of a class of e-commerce systems, elaborated within an IT foresight project financed by the European Regional Development Fund (ERDF) and carried out in Poland since January 2010.

Objectives

As it is clear that the sole use of both classical econometric methods and narrative descriptions have proved to be insufficient to get adequate IT foresight results, the main objective of this paper is to extract, formulate and analyse the general rules and principles that govern the evolution of key information technologies, the IS itself, as well as society and the economy as a whole. The results should be constructively applied to developing technological policies and strategies at different levels, from corporate to multinational. The study of differentiated factor interactions, modelled in a different way, led to the application of modern modelling methods such as discrete-event-systems, multicriteria analysis, and discrete-time control. Although the general applicability field of these methods is generating trends and scenarios in a foresight exercise, they can also be used to better understand the role of global Information Society Technologies (IST) development trends and to develop IS and IT policies in an optimal control framework.

A number of partial goals have been defined, which might help to achieve the ultimate objective described above as well as being independent research aims in their own right. These include:

- An ontological knowledge base which stores raw data together with IS/IT models, trends and scenarios in the form of so-called proceedings (records of operations) containing data together with records of their step-by-step analyses and results;
- Methods of multicriteria rankings suitable for IT management and capable of generating constructive recommendations for decision-makers;
- A penetrative analysis of several real-life industrial applications in selected technological areas submitted by industrial partners cooperating on the implementation of the project's results.
- A detailed analysis of technological trends and scenarios in selected areas such as expert systems, decision support systems, recommenders, m-health, neurocognitive technologies, quantum and molecular computing.

Any of the above partial objectives should provide useful solutions to the technology management problems presented by the companies involved in the exercise, allowing them to apply the knowledge gained to set strategic technological priorities and formulate IT and R&D investment strategies. This is discussed further in Sec. 6.

Methodology

The main research topic investigated here can be described as follows: *how the development of the IS in a country, or a group of countries, depends on the global IT development processes and on integration of the IS around the world, driven by the global trends*. As regards the latter, various factors must be considered such as falling telecommunication prices, exchange of information through the internet, rapid diffusion of information on innovations and technologies, and free access to web information sources. The civil society evolution, driven by the growing availability of e-government services and related web content, has been taken into consideration as well. Finally, the psychological and social evolution of IT users, including all positive and negative i-inclusion phenomena will be taken into account as a set of feedback factors influencing the legal and political environment of the IS.

Due to the complex nature of the Information Society, it is difficult to create a model that is clear, unambiguous and concise. One of the aforementioned FISTERA project's findings was that the composite indicators based on statistical data rarely provide an adequate description of the IS system's dynamics. Therefore when performing the research described in this paper, it was decided that the use of aggregates as the basis of forecasts and recommendations should be avoided. Instead, we have introduced a new class of input-output models that fit well into the IS specificity. In particular, we have defined eight to ten major elements of an IS, such as population and its demographics, legal system and IS policies, ITs in personal and industrial use, etc. (cf. Figure 1).

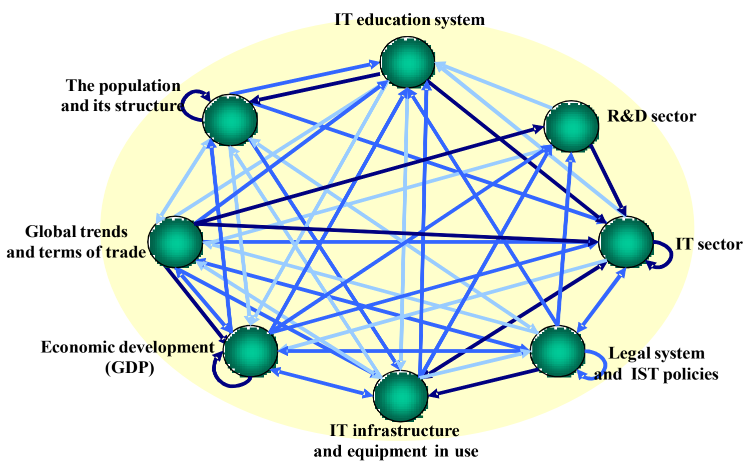

Figure 1. A causal graph linking the major subsystems influencing the development of the Information Society: dark blue arrows denote strong direct dependence, medium blue indicates average relevance of causal dependence, and light blue denotes weak direct dependence between subsystems

These elements correspond to the subsystems of the IS, and are related to the IT/IS development trends evidenced in the past that are supposed to be able to effectively characterise the IS evolution. During analysis, each appears as a bundle of discrete events, continuous trends and continuous or discretised state variables. The evolution of the IS is then modelled as a discrete-continuous or discrete-event system, where the mutual impacts of each of the elements are represented either in symbolic form, as generalized influence diagrams, or within state-space models. Some external controls, such as legal regulations and policies, are modelled as discrete-event controls, while the others, such as tax parameters or the central bank's interest rates should be included in the discretised part of the model. Other exogenous (non-controlled) variables include exchange rates, energy prices, demographic structure, attitude towards IT-related learning and so on. Technological trends form inputs, while feedback loops allow us to model the influence of technological demand on the IT, R&D, production and supply, as well as on overall GDP growth rates. An interesting observation resulting from an analysis of the past trends is the periodic occurrence of time gaps between the IT technologies, product trends and market expectations, a phenomenon that led to the failure of Lisa in the 80's but contributed to the recent success of iPod. Another lesson based on the past trends is the model of adaptation of new versions of software to the progress in the development of processors, storage and peripheral devices.

A causal graph of the underlying dynamical model is presented in Fig.1 above. Only direct impacts, i.e. those which show immediately or within one modelling step are marked. The indirect impact may be obtained by multiplying the coincidence matrix associated with the directed direct impact graph by itself.

Let us recall that a *discrete-event system* can be described as a 5-tuple *:*

$$P=(Q,V,\delta,Q_0,Q_m) \qquad (1)$$

where:

Q – is the set of system states,

V – the set of admissible operations over the system,

$\delta: V \times Q \to Q$ – the transition function governing the results of operations over states,

Q_0 - the set of (potential) initial states of the process,

Q_m – the set of final (or reference) states.

A pair of states $e:=(q_1,q_2)$, such that $q_2=\delta(v,q_1)$will be termed *an event.* The set of all admissible events in the system (1) will be denoted by E. Following the above assumptions concerning the controlled discrete-event variables, the operations from V may be either controls, i.e. the decision-maker's actions over Q, or may occur spontaneously as the results of random processes. Furthermore, we assume that there exists a set $X(Q)$ of quantitative or ordinal characteristics of states from Q, which can be deterministic, interval, stochastic, fuzzy etc. One of the coordinates of G can be (but does not need to be) identified with time. *An elementary scenario s* is a sequence of events $(e_1,\ldots,e_p)$, such that if $e_i=(q_i,q_{i+1})$ then $e_{i+1}=(q_{i+1},q_{i+1+2})$. In order to conform with the usual foresight definition of scenarios, a scenario will be defined as a cluster of elementary scenarios, where the clustering is based on certain similarity rules applied to linked events.

After scaling the dynamics based on past observations, key IS characteristic trends can be described quantitatively as solutions to discrete-time dynamical systems of the form

$$x_{t+1}=f(x_t,\ldots x_{t-k},u_1,\ldots,u_m,\eta_1,\ldots,\eta_n), \qquad (2)$$

where $x_t,\ldots x_{t-k}$ are state variables, $x_j:=(x_{j1},\ldots x_{jN})\in IR^N$, $u_1,\ldots,u_m$, are controls, and $\eta_1,\ldots,\eta_n$ are external non-controllable or random variables. In the IS models analysed so far, f has always been a linear non-stationary with respect to x, and stationary with respect to u and η.

Discrete-event and discrete dynamical systems may jointly govern the evolution of causal systems, thus providing a tool to construct elementary scenarios, which appear as trajectories to (1)-(2). Consequently, when using models (1)-(2) to generate optimal strategies or policies, the goals should be quantified and associated with events and elementary scenarios. A generalisation of the multicriteria shortest-path algorithm should then be applied to variable-structure networks that appear in the optimal control of discrete-events (cf.) and discrete dynamical systems.

To complement the quantitative-symbolic analysis, a new method of IS expert assessment has also been developed, namely a dynamic generalisation of the SWOTC analysis (SWOT with "Challenges" as an additional element,) that also includes the detection of real options emerging in the system for its principal stakeholders. Used as a dynamic TOWSC (TOWS with "Challenges" as above), it allows us to characterise the IS and its development prospects more effectively. The combination of the dynamic evolution model, Data Envelopment Analysis (DEA), and SWOTC yields a dynamic benchmarking scheme, that enables us to compare different information societies, identify their dynamics, and provide aggregate group characterisations.

Technologies and Developments

The overall foresight process has been organised within the framework of expert systems, as an ontological knowledge-base coupled with autonomous web crawlers and analytical engines. The scheme is presented in Figure 2. below.

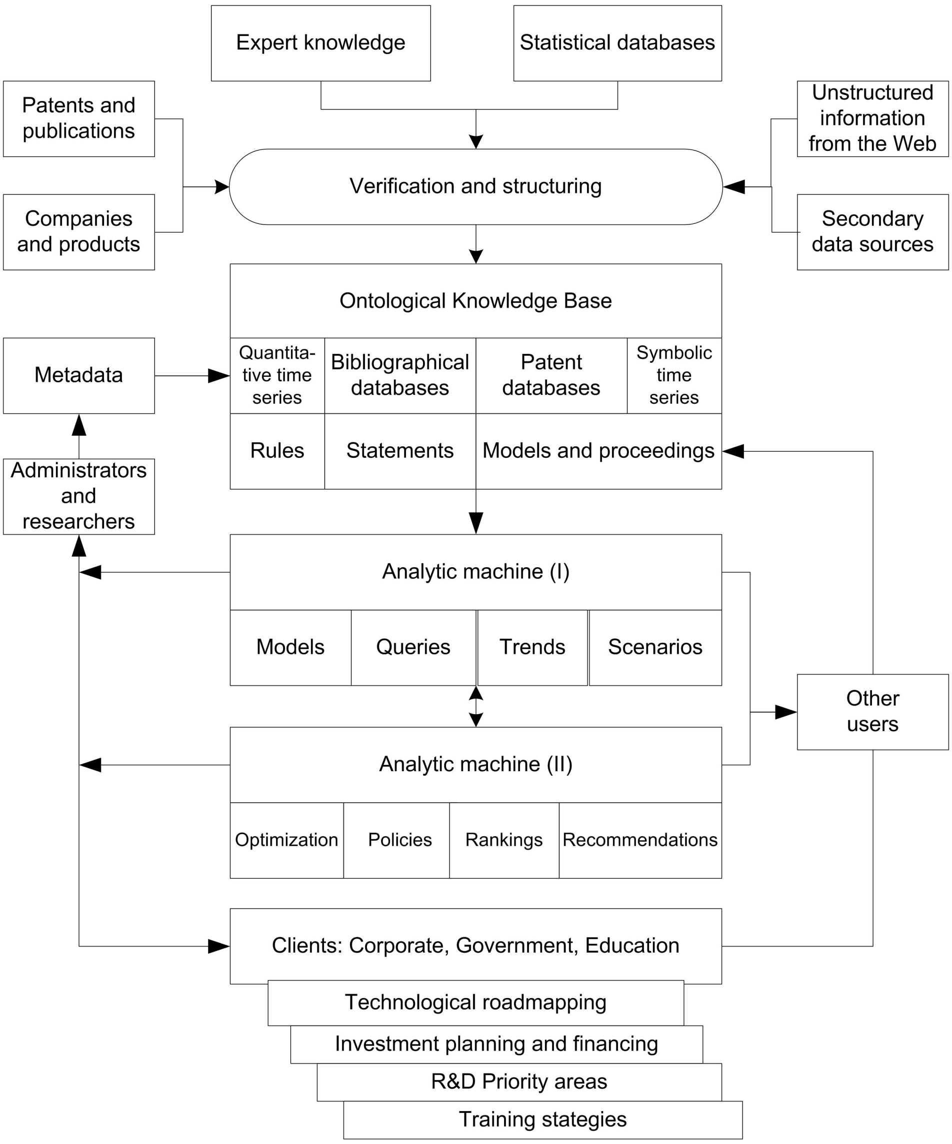

Figure 2. The Foresight Knowledge Processing Scheme

Any query from a client can be processed by making use of a common database, containing global trends and general development models, as well as context-dependent information related to the specific area of the query.

The knowledge base shown above can itself be regarded as an interesting instance of a decision support system. It includes ontology management functionality, specifically ontology merging and splitting, time evolution, operations on metadata, data updating protocols. The usual data warehousing functionality has been implemented as well, including automatic updating. Other functionalities, such as content marketing, are planned for a later date.

The technological focus areas of the project, which are also reflected in the scope of knowledge gathered and processed by the above system, are listed below:

- Basic hardware and software technologies,
- Key IS application areas (e-government, e-health, e-learning, e-commerce),
- Expert systems,
- Machine vision and neurocognitive systems,
- Molecular and quantum computing.

The thematic databases store the above area-specific information, while a common data block contains interdisciplinary information to be used during thematic analyses, such as macroeconomic data, social characteristics (employment, education, demographics), geographic information, and other data potentially useful in providing decision-making support.

A number of specialised algorithms are contained in Analytic Machines I and II, including a.o. trend-impact and cross-impact analysis, consumer' preference models, specific sector and market models concerning education and health care services, media, internet advertising, quantitative information markets, as well as a package of adaptive trend algorithms. Recommendations are generated making use of multicriteria outranking methods, some of them developed solely for IT prioritisation problems.

The knowledge gathered in the system is continuously updated, represented and processed using Bayes and other types of causal networks, automatic rule generation techniques, and anticipatory feedback models.

Results and Policy Implications

The new approaches outlined above have made it possible to elicit trends and build technological and social scenarios in a more effective way, as well as visualise their evolution. The scenarios can again be used to re-examine IS evolution principles, which all constitute a consistent interactive and adaptive evolution model. It allows us to characterise the technologies or the IS as a whole, as well as rank and position the countries or regions under review in terms of IS development. As EU cohesion policy places emphasis on bridging the digital divide, which can be measured during a benchmarking process, more objective and quantifiable future IS characteristics will enable us to define more appropriate policy goals and measures to implement. This can be especially important when re-evaluating the Community's budgetary policies for the new planning period of 2013-2020, where the expected benefits from IS/IT spending should be well justified by objective scenarios and forecasts, taking into account the implementation of policies under financial crisis circumstances.

The main user group of the methodology and future information system are innovative IT companies seeking technological recommendations, advice concerning R&D priorities, as well as corporation from different sectors that invest in IT. The global trends identified and technological characteristics of the IS evolution can provide clues to policy-makers as well as R&D and educational institutions on the key directions of development, and on the demand for IT professionals.

Business Benefits

Foresight results can allow corporations to determine an adequate level of funds to allocate for IT investment over a relatively long-term period as part of the company's overall strategic decision making. For IT, this can range between 10 and 15 years, while for related R&D it can reach a planning horizon of 30 years . Foresight outcomes can situate the IT project portfolio management and fund allocation strategies within the macroeconomic, political, technological and research environment by providing recommendations, relative importance rankings, trends and scenarios. The quantitative characteristics of the IT and IS evolution can provide direct clues to IT providers as regards future demand for their products.

The implementation of IT foresight results in a company may be modelled by a hierarchical multicriteria decision problem that explores the results of external (foresight-based) advice with a set of internal criteria describing the preferences of shareholders as well as the degree of achievement of the company's long-term market and investment targets. The above-mentioned problem may admit various forms, depending on the company's needs and foresight outcomes available. This section will examine a real-life example of a Polish Cracow-based investment fund focused on 3D and virtual reality technologies for modern e-commerce applications that takes into account IT development trends and rankings of prospective products, technologies and markets elicited during a foresight exercise. At a higher decision-making level, dynamic ranking methods are used to rank corporate development policies, which concern the sector, size, or regional preferences regarding targeted markets or portfolio structure (cf. e.g.). At the lower decision-making level, rankings are implemented as investment rules, by assigning funds to specific undertakings. Each assignment is a function of time and of external logical variables, the latter representing the changes in higher-level ranking and the states of external socio-economical (including the financial markets) situation and research environments. The foresight scenarios are used to establish future investment rankings in an adaptive way. In particular, based on the feasible scenarios found at moment t_0, the management of the fund can calculate corresponding future rankings for $t= t_0+1, t_0+2,\ldots,t_0+k$. This makes it possible to input into fund allocation planning more knowledge coming from systematically updated foresight results in the form of future recommendations and real options than when applying a usual static approach.

According to a needs analysis performed in 2009 on the companies listed on the Warsaw Stock Exchange, the most needed IT foresight applications relate to new product development, while foresight information on technological prospects and consumer preferences is used to minimise investment risk and increase the company's competitiveness. The structure of respondents' interests is shown in Figure 3.

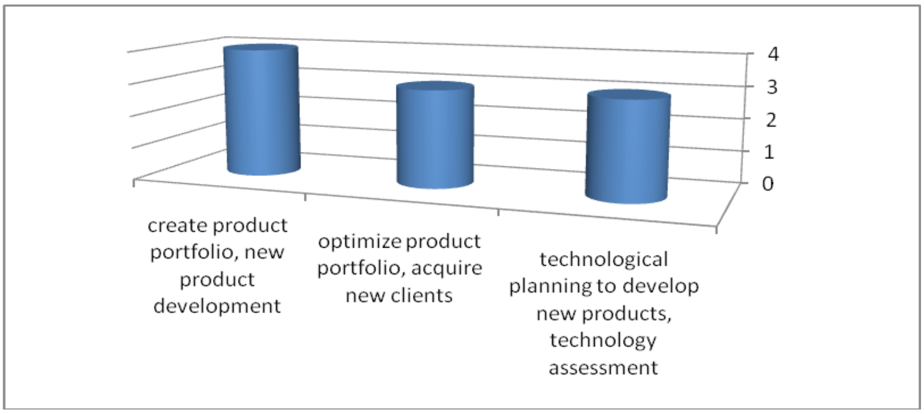

Figure 3. Declared Goals of IT Companies Intending to Apply Foresight Results. Source: P&BF, 2009

Apart from rationalising the time order, financing IT and market expansion projects, higher-level investment policy ranking may also help to determine organisational structure and human resource characteristics, future budgetary needs, and actions to be taken when priorities change as a result of an external event.

Conclusions

Comparing quantitative and descriptive approaches to elicit trends and build scenarios, it is noticeable that the approach of extracting evolution rules prior to scenario analysis proves especially useful in case of converging information societies, as exemplified by IST trends in the EU States which acceded in 2004 and 2007. The progress of the cohesion process five years after the first IS foresight results in these countries were published confirms that the modelling methods developed and applied have been adequate, and have yielded a good coherence of forecasts and their ex-post verification.

Therefore, the further development and use of these methods, as described in this paper means that rational results in form of trends, scenarios and rankings for the following 12-15 years can be expected. This could have useful applications in planning corporate strategic IT development. In particular, the results that have arisen so far from the investigation of selected technology areas within the new ERDF-financed IT foresight exercise, i.e. decision support and recommender systems, can provide constructive recommendations to companies interested in the development of e-commerce applications. Moreover, the general IS evolution model outlined in Sec. 3 proves useful for the analysis of global IT and socio-economic trends that influence the development of the IS in a country or region.

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