Future Trends of Intelligent Decision Support Systems and Models

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Abstract. The aim of this paper is to investigate, formulate, and analyse the general rules and principles that govern the evolution of key factors that influence the development of decision support systems (DSS) and models. In order to elaborate a model suitable for medium-term forecasts and recommendations, we have defined eight major elements of Information Society that characterise the evolution of the corresponding digital economy. The evolution of the overall system is described by a discrete-continuous-event system, where the mutual impacts of each of the elements are represented within state-space models. Technological trends and external economic decisions form inputs, while feedback loops allow us to model the influence of technological demand on IT, R&D, production, and supply of DSS. The technological characteristics of the product line evolution modelled in this way can provide clues to software providers about future demand. They can also give R&D and educational institutions some idea on the most likely directions of develop¬ment and demand for IT professionals. As an example, we will model the evolution of decision-support systems and recommenders for 3D-internet-based e-commerce, and their impact on technological progress, consumption patterns and social behaviour. The results presented here have been obtained during an IS/IT foresight project carried out in Poland since 2010 and financed by the ERDF.

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

1 Introduction and Objectives

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 stimulating the development of the IS. This, in turn, has made it possible to draw more general conclusions

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regarding the evolution of the IS in Europe and its future scenarios as well as to study the future development of selected information technologies (IT) and application areas. Some of these findings were first described in a series of reports [4] 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.

Other recent EU projects devoted to the investigation of the development of the Information Society include SEAMATE (Socio-Economic Analysis and Macromodelling of Adapting to information Technologies in Europe [13]) and ISCOM [5]. New trends, processes, and phenomena concerning the current and future state of the IS have been observed, and several case studies can be referred to in [4,12]. The progress achieved in [12], compared to earlier work on IS models, cf. [1,6,7,13], lies in the appropriate use of statistical data concerning IS indicators. The research projects mentioned above have shown i.a. that the sole use of classical econometric methods and narrative foresight descriptions have proved to be insufficient to get industry-oriented IT foresight results. Another observation, relevant to the scope and results of this paper, is that any individual IT is embedded in a complex technological, economic and social system in such a way that its evolution cannot be explained without investigating this system in a holistic way. This touches upon as well an important class of applications, the decision support systems (DSS), which has been the subject of prospective studies presented in this paper. This is why, despite the scarcity of published research results on the future trends of DSS, (cf. e.g. specific-application-oriented papers [8,7,] or the bibliometric trend analysis in [3]), we can benefit from the general methods and results derived within the above mentioned projects for the IT - from the providers' point of view, and IS – from the users' one.

To sum up, the methods presented here as a background to elicit trends and elaborate scenarios of decision-support and decision-making systems can constitute an input to any IS/IT foresight exercise. We will also present the conclusions regarding the development of a cluster of new classes of e-commerce systems, coupled with recommendation engines, that have been elaborated within an IT foresight project [8]. 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. The results should be constructively applied to developing technological policies and strategies at different levels, from corporate to multinational. Trends and scenarios thus generated can 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.

To achieve the ultimate objective described above a few intermediate research goals have been defined. These include:

- An information system, consisting of an ontological knowledge base which stores raw data together with the appropriate technological models, trends and scenarios in the form of so-called proceedings containing data together with records of their step-by-step analyses and results. This information can be used as input to multicriteria rankings methods suitable for IT management and capable of generating recommendations for decision-makers as regards the prioritization of IT investments.

- A detailed analysis of several real-life industrial applications of decision support systems in selected technological areas submitted by industrial partners cooperating on the implementation of the project's results, including an analysis of technological trends and scenarios in areas such as virtual-reality-based e-commerce, expert systems, recommenders, m-health, neurocognitive technologies.

The achievement of the above goals should provide useful solutions to the technology management problems presented by the companies involved in the project, 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. 3.

2 Modelling Methodology

One of the research questions that could be posed by a user of a technological knowledge base investigated here could read as follows: *how the development of selected information technology depends on the global IT development processes and on integration of the IS around the world, driven by the global trends*. We investigate this question in more detail in the next Sec. for the case of decision-support methods and technologies. As regards the global environment, various factors must be considered such as falling telecommunication prices, exchange of information through the internet, rapid diffusion of information on innovations and technologies, the development of e-commerce, 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 has been 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 decision-support technologies, that rely strongly on the cognitive and social phenomena, it is difficult to create a technology evolution model that is clear, unambiguous and concise. One of the aforementioned FISTERA project's findings [12] was that the composite indicators based on user data rarely provide an adequate description of the technology parameter 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 specificity of this kind of technologies. In particular, we analyze different groups of potential users separately that might eventually explain the development of separate product lines. To cope with the high level of system's interconnectedness, we have defined eight major elements of an IS, such as population and its demographics, legal system and IS policies, ITs in personal and industrial use, etc. (cf. Fig.1) that can influence the technological evolution. The relations between different groups of users of DSS are described at this level only.

These elements correspond to the subsystems of the IS, and are related to the IST development trends evidenced in the past that are supposed to be able to effectively characterise their evolution. During analysis, each appears as a bundle of discrete events, continuous trends and continuous or discretised state variables. The evolution of the IST is then modelled as a discrete-continuous-event system, where the mutual impacts of each of the elements are represented either in symbolic form, as generalised 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 are 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 and external economic decisions form inputs, while feedback loops allow us to model the influence of technological demand on IT, R&D, production and supply of selected information technology or its products, as well as on overall GDP growth rates. Another lesson from 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. The technological characteristics of the product line evolution modelled in this way can provide clues to software providers about future demand. They can also give R&D and educational institutions hints on the most likely directions of development and demand for IT professionals.

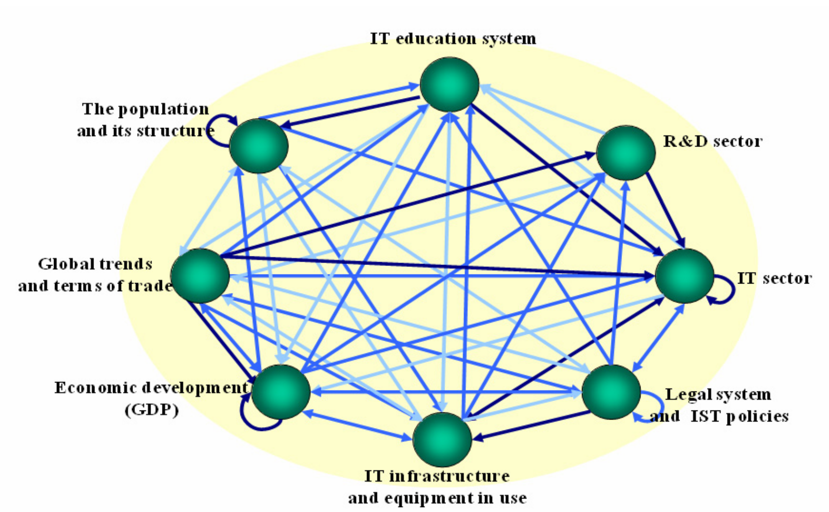

Fig. 1. A causal graph linking the major subsystems that can influence the development of an IT area: dark blue arrows denote strong direct dependence, medium blue indicates average relevance of causal dependence, and light blue denotes weak direct dependence between subsystems

A causal graph of the underlying dynamical model derived from an expert Delphi [9] 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 impact graph by itself.

Let us recall that a *discrete-event system* can be described as a 5-tuple [11]*:*

$$P=(Q,V,\delta,Q_0,Q_m) \tag{1}$$

where Q – is the set of system states, V – the set of admissible operations, $\delta: V \times Q \rightarrow Q$ – 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 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. Further, 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 definition of scenarios, we define a *foresight scenario* as a cluster of elementary scenarios, where clustering is based on certain similarity rules applied to events.

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

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

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 models analysed in [8], f has been linear non-stationary with respect to x, and stationary with respect to u and η.

Discrete-event and discrete-time control systems may jointly govern the evolution of causal systems, thus providing a tool to elicit trends and construct elementary scenarios, which appear as trajectories to (1)-(2). Consequently, when using (1)-(2) to generate optimal technological strategies or investment policies, the goals should be quantified and associated with events and elementary scenarios. A generalisation of the multicriteria shortest-path algorithm for variable-structure networks can then be applied to the optimal control of discrete-events [11] and discrete dynamical systems.

To complement the quantitative analysis, a new method of expert assessment has been developed, namely a dynamic generalisation of the SWOTC analysis (SWOT with "Challenges" as an additional element [12]) that also includes the detection of real options emerging in the system for its principal stakeholders and allows us to characterize the IS technologies development prospects more effectively.

The overall foresight process has been organized within the framework of expert systems, built into an ontological knowledge base coupled with autonomous web-crawlers and analytical engines. The knowledge base with its analytical capabilities and automatic knowledge acquisition, update and verification, can itself be regarded as an instance of a decision support system. It includes ontology management functionality, specifically ontology merging and splitting, time evolution, operations on metadata, data updating protocols as well as other data warehousing functionalities.

The technological focus areas of the foresight 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, including decision support systems and recommenders

- Machine vision and neurocognitive systems,
- Molecular and quantum computing.

Out of the list above, the research on first four listed focus areas has been used to elicit development trends of decision support and autonomous decision-making systems for the next 15 years. 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.

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. Thus the development of decision support technologies, that is described here, could be extracted from the overall knowledge base by a small set of queries.

3 Future Intelligent DSS and Their Applications

The new approaches outlined above have made it possible to elicit trends and build technological scenarios concerning the decision support systems and to visualise their evolution. In particular, we have identified the key development topics of expert systems/DSS [9], listed according to the relevance scores (first best) as follows:

- recommenders for e-commerce (excluding banking and finance)
  - graphical (content-based) recommenders for multimedia
  - graphical (content-based) recommenders for 3D-e-commerce
  - recommenders able to judge on product portfolios (constrained by its value)
- recommenders for security and commodity trading
- intelligent intermediary agents for negotiations, partner matching, collaboration.

Among the key technologies, methods and models to be used in DSS, the following appeared in most of the experts' recommendations:

- GIS technologies, able to evaluate or elicit preferences as regards individual sites in a large region, making an intensive use of visualisation, and coupled with GPS
- Cognitive features of expert systems, allowing one to eliminate the negative consequences of decisions made in a hurry, or by a nervous decision-maker etc.

Some of the salient trends concerning the future DSS (until 2025) that have been identified in [9] and relate to the 3D-e-commerce applications, are listed below:

- the role and the sophistication degree of OR-based methods applied in DSS will increase; especially multicriteria optimization, uncertainty models and management,
- the class of decision problems regarded as numerically non-tractable will shrink,
- the DSS (including and starting from recommenders) will converge with search engines and intelligent data mining agents; the latter will complete missing data that might help in solving decision problems supplied in client's queries.

Although most information provided in pilot Delphi interviews was qualitative, some of the trends elicited could be characterised quantitatively, see Tab.1 below. The trends thus obtained allow us to characterize the selected technologies, rank and position the companies, countries or regions under review in terms of development of the particular technological area as well as to give hints on how to design tailored Delphi research to address more specific issues. The future characteristics concerning the DSS market are helpful in assessing the competitiveness of DSS suppliers as well as individual products that can be accomplished during an interactive benchmarking process, using DEA or other performance measures.

Table 1. Some quantitative DSS characteristics according to an expert Delphi (average values)

Trend description	Present state	Value in 2020	Value in 2025
Penetration of the mobile DSS in OECD countries	2%	50%	80%
Seeking advice from an online medical DSS (EU)	15%	45%	70%
DSS as a component of social media	5%	60%	95%
Share of DSS using multicriteria analysis (except simple weighting methods)	35%	50%	80%

The specification of key technologies, focus areas, methods and models allowed, in turn, to focus research on trends and scenarios concerning the selected objects. The scenarios can then be used to re-examine technological evolution principles in the knowledge base, forming thus a consistent interactive and adaptive evolution model.

The main user group of the foresight exercise outputs, recommendations, and future information system described in Sec. 2 are innovative IT companies seeking technological recommendations, advice concerning R&D priorities, as well as corporation from different sectors that invest in IT. Moreover, 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.

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 [9]. 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. More objective and quantifiable future technological and economical characteristics will enable us to define more appropriate policy goals and measures to implement. The quantitative characteristics of the technological evolution can provide direct clues to IT providers, specifically the DSS, 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.

A real-life example of such industrial foresight user is a 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. 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 on the companies listed on the Warsaw Stock Exchange recently, 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 Fig.2 below.

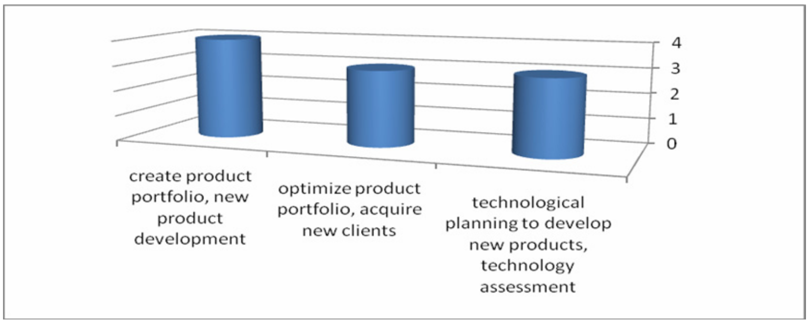

Fig. 2. The declared goals of 10 Polish IT companies seeking foresight results [9]

Apart from making the time order rational, 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.

4 Conclusions

Comparing quantitative and descriptive approaches to elicit technological 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, and converging technologies, such as DSS. Although the data used to derive the IS/IT trends presented in this paper origins mostly from Poland and other EU States which acceded in 2004 and 2007, the global IS/IT trends have been taken into account as well. A good coherence of forecasts and their ex-post verification five years later validates the modelling methods used first in [12] and confirms the adequacy of the general IT/IS evolution model outlined in Sec.2 for the analysis of global trends that influence the development of the digital economy in a country or region.

In particular, the recent developments of distributed, grid-, and cloud-computing-based decision support systems [2,10] indicate that after the first revolution that occurred in mid-80's, namely the migration from the mainframe-based to PC-based DSS, and after the second one, at the end of 90's, when web based DSS started to dominate and first common web recommenders were created, nowadays we face another challenging period in the development of this class of applications. It is likely to be characterized by an increased role of collective decision making tools, including social decision computing, decision grids and clouds, a growing relevance of cognitive features implemented in the DSS, advanced options allowing to express more creativity by the decision-makers, the use of sophisticated MCDM methods, virtual reality with all its attributes and a growing degree of realism, to list only a few.

The second conclusion refers to the methodology rather than to foresight results. Namely, the use of methods described in this paper shows that for the technologies changing as rapidly as DSS one can expect rational foresight results in form of trends, scenarios and rankings for the time horizon of about 15 years. This planning perspective should be sufficient for most corporate strategic IT development decisions and for all IT investment decisions by non-IT companies as the legal and real depreciation periods for this type of investment are much shorter. Finally, let us mention that in the area of decision support systems, the results of the ERDF-financed IT foresight project [9] could provide constructive and successful recommendations to companies interested in the development of novel e-commerce applications.

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