Future Prospects of Selected Intelligent Decision Technologies and Their Deployment in Information Systems

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Abstract

This paper presents an overview of technological prospective studies on selected classes of decision support and intelligent information systems. Technological trends and scenarios were generated from simulation experiments with hybrid models consisting of discrete-time control and discrete-event components. These trends were then merged with the outcomes of an innovative Delphi survey. Both techniques yielded a complex information technology model, capable of describing various factors relevant to the evolution and adsorption of intelligent technologies. Specifically, we investigated the development of intelligent decision support systems, recommenders, and specialized information systems supporting e-commerce, e-science, e-learning, and crisis management. The technological evolution model features software development paradigms such as DevOps, Next Release choice, and competition among system suppliers. Additionally, the survey highlighted customers' preferences and market prospects. The foresight results are presented in the context of overall progress in information systems, software market needs, and user behavior.

Keywords: Foresight support systems, Intelligent information systems, Decision support, Technological evolution, Delphi survey.

1. Introduction

This paper presents the methodological background and selected outcomes of recent intelligent technologies foresight. We focused our attention on intelligent decision support systems (DSS) and recommenders futures, as well as on specialized information systems (IS) supporting e-commerce, e-science, e-learning, e-health, disaster resilience and crisis management. Besides the cognitive advantages in better understanding the technological and research futures, this study provides outcomes of practical importance, namely:

- Viability assessment of IS, based on the analysis of offering new functionalities to users and next release generation strategies [5] in the competitive market context.
- Eliciting new approaches and best practices in IS development, that merges DevOps [4] with foresight- and forecasting-based technology alignment, and with user engagement in IS development and testing according to the Living Labs paradigm.
- Setting priorities in IS education, research, as well as start-ups and SME fostering policies, based on technological development prospects and user preferences concerning futures rather than focusing solely on market needs and user experience [6].

The above highlights resulted from an application of a novel technology evolution model that included software engineering paradigms and the impact of IS development and deployment on the economy and society at large [7-8]. Economic and technological trends were elicited from publicly available statistical data, analytical technology reports, AI market data, and from expert responses in a Delphi survey. Technological forecasting has been carried out with tools elaborated earlier within the research project SCETIST [15] and its follow-ups. The investigation of IS futures focused on the uses of selected artificial intelligence (AI) technologies in IS, specifically intelligent decision support and autonomous software agents. Time series were processed and forecasted via simulation of a hybrid model that consisted of discrete-time- and discrete-event components with controls [8]. Judgmental forecasts and missing impact coefficients were combined with the outcomes of econometric technology development modelling, yielding a complex technology evolution model. The social, economic, and R&D indicators describing the production and adsorption of intelligent technologies in the modelled economy were considered as outputs from the aforementioned control system. The collaborative system dynamics model building was supplemented by a quantitative forecast-oriented innovative web-based Delphi survey [11], where the respondents expressed their opinions on future values of selected technological and market indicators at the predefined forecast horizons. Both techniques were combined with dynamical ranking and recommendation provision, as well as anticipatory socio-economic impact models [9], forming a hybrid holistic model of technology evolution in social, economic, and environmental contexts [16].

The next section is devoted to the presentation of IS-related foresight methodology, specifically to the background principles of the foresight support system, which is an IS in its own right. A brief report on resulting user-oriented IS development trends is provided in Section 3. Among the intelligent technologies studied with our foresight support tools, particular attention was paid to the development of decision support systems (DSS) and recommenders [10], as well as to AI-based knowledge repositories and learning platforms (AILPs, [12]). An ongoing Delphi exercise is devoted to modelling the evolution of disaster resilience support systems, crisis management systems, and their economic and social impacts [14]. This exercise, its solicited results, such as future scenarios will be discussed in the concluding Section 4 along with the impacts on the overall progress in IS, global IT and economic trends, and social changes related to the pandemic crisis.

2. Methodology and Scope of Technological Prospective Studies

The foresight process is based on a discrete-time/discrete-event hybrid model of technological evolution in the Information Society context. Data processing has been organized within the framework of specialized expert systems, termed foresight support systems (FSS, [16]). This class of expert systems is distinguished by the special attention paid to combining qualitative expert knowledge acquired in Delphi and similar exercises with quantitative trends and forecasts. Another feature of FSSs is their ability to account for various kinds of knowledge, such as patent or bibliographic data fed by automatic web crawlers in real-time, and process them in a uniform way as quantitative trends.

Technological evolution is modelled in the FSS as a discrete-continuous-event system [8]. Its parameters can be identified based on past observations using vector time series smoothing approaches. It can be described by the following recursive equation:

$$x_{t+1}=f(x_t,\dots,x_{t-k}, u_{t,1},\dots,u_{t,m}, \eta_{t,1},\dots,\eta_{t,n}, t), \quad (1)$$

where all variables are defined on a certain discrete time interval, i.e. $t\in[t_0:T]$, namely:
$x_t,\dots,x_{t-k}$, are state variables, $x_j:=(x_{j1},\dots,x_{jN})\in\mathbb{R}^N$, socio-economic and technological indicators,
$u_{t,1},\dots,u_{t,m}$ are controls, $u_{t,i}\in[u_{t,i-}, u_{t,i+}]$, for $i=1,\dots,m$, that describe technological investments,
$\eta_{t,1},\dots,\eta_{t,n}$ are decisions of external (non-controllable) decision makers or random variables.

The function f is assumed to be linear nonstationary with respect to x, and stationary with respect to u and η. The coefficients of f were identified using maximum likelihood methods on stationarity subintervals of the modeling period $[t_0,T]$, based on Eurostat time series.

The discrete-time control model (1) is supplemented by a discrete-event system P [8] that represents the dynamics of discontinuous variables, namely

$$P=(Q, Q_0,V,\delta), \quad (2)$$

where:
Q – is the set of all feasible states of event-driven model components,
Q_0 – is the set of initial states of event-driven model components,
V - is the set of admissible operations over states, derived from decision rules, legislation process principles, rules governing R&D and innovation, software development, etc.,
$\delta: V\times Q\to Q$ – is the transition function governing the results of operations over states.

Events in P are defined as pairs of states $e:=(q_1,q_2)$, such that $q_2=\delta(v,q_1)$. The operations from V may be either controls, i.e. the decision maker's actions over Q, or may occur spontaneously as the result of random processes. The sequences of events may be linked by trends and include external events as causes, thus forming *extended episodes*. These are then clustered to form k scenarios. General technological and economic trends as well as user requirements form inputs to the control system (1) that may be endowed with feedback [8]. The output variables $y=(y_1,\ldots,y_p)$ for (1)-(2) are indicators describing the technologies of interest or modelling the demand for selected AI tools and services. Quantitative indicators describing basic information technologies (IT) served as input or explanatory variables for intelligent technologies and their applications.

Continual information acquisition, knowledge management, and AI tools have been combined in a holistic FSS, which allowed us to achieve the following research aims:

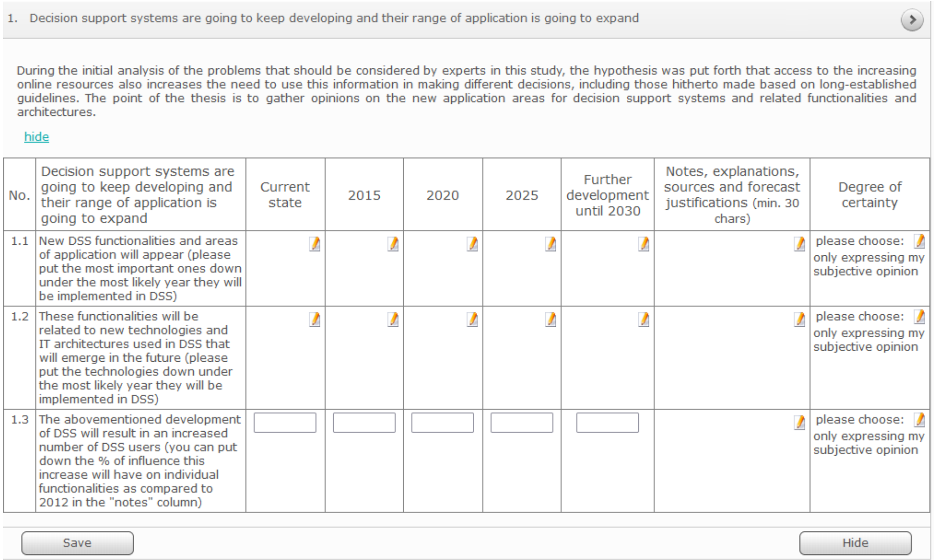
- Designing, implementing, and linking with the FSS an ontological knowledge base that stores time series and other data together with technological, economic, and social evolution models, trends, and scenarios.
- Selecting and applying multicriteria outranking algorithms suitable for assessing AI-related technologies and capable of generating constructive recommendations for decision makers in regard to strategic technological priorities and IS development strategies.
- Implementing an FSS-specific analytic engine equipped with well-known foresight methods such as trend-impact, cross-impact analysis, scenario clustering, and roadmapping.
- Linking newly developed methods to explore the future based on rational decision elicitation and decision consequence models, such as causal and anticipatory networks [9].

The Delphi survey has been selected as the technique allowing a foresight exercise organizer to elicit trustworthy expert knowledge on topics that were otherwise hard to acquire. It consists of selecting knowledgeable experts and inviting them to respond to a set of questions concerning plausibility, probability, or timing of future events, trends, or relations. Each question may be asked several times, upon an ensemble of responses is gathered. This element of the survey is called a round. In the 2nd and further rounds, the statistical analysis of former responses and their justifications are shown to the respondents. This is a learning process that may ultimately lead to a consensus among experts, i.e. to the situation where all responses can be grouped in one cluster with a predefined intracluster homogeneity. The rounds are repeated until either a consensus or an informed and argument-supported dissent among expert responses is reached. In the latter case, clusters of similar responses may be regarded as distinct scenarios of the future.

The online multi-round Delphi first used in SCETIST [15] and MOVING [12] projects offers a flexible approach, termed extrapolation Delphi, capable of continually gathering expert views and building a consistent fusion of them. The multi-round mode can be combined with real-time Delphi [11], where experts can immediately view the results of survey analysis. In the combined mode, progressing to the next round is possible upon collecting a specified minimum number of responses from the previous round. Moreover, this survey software allows its users to conveniently manage the experts' credibility.

3. The Outcomes of DSS Requirement Modelling

DSSs endowed with intelligent tools have been the technological focus area of requirement analysis, performed with the FSS outlined in the previous section. This analysis comprised several components related to user requirements, AI needs, organization of the DSS development process, as well as to economic and social impacts. We present below the analysis related to the first component, which was based on responses to the Delphi survey. The respondents (N_1=70 for 2020, N_2=59 for 2025, N_3=51 for 2030) were requested to identify the required DSS functionalities, application areas and IT architectures that will emerge or become relevant at one of the three time horizons (2020, 2025, and 2030), cf. Fig. 1. The historical values for 2015 from a previous survey and the current state were used as a basis to assess the meaningfulness of the responses.



1. Decision support systems are going to keep developing and their range of application is going to expand

During the initial analysis of the problems that should be considered by experts in this study, the hypothesis was put forth that access to the increasing online resources also increases the need to use this information in making different decisions, including those hitherto made based on long-established guidelines. The point of the thesis is to gather opinions on the new application areas for decision support systems and related functionalities and architectures.

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No.	Decision support systems are going to keep developing and their range of application is going to expand	Current state	2015	2020	2025	Further development until 2030	Notes, explanations, sources and forecast justifications (min. 30 chars)	Degree of certainty
1.1	New DSS functionalities and areas of application will appear (please put the most important ones down under the most likely year they will be implemented in DSS)							please choose: only expressing my subjective opinion
1.2	These functionalities will be related to new technologies and IT architectures used in DSS that will emerge in the future (please put the technologies down under the most likely year they will be implemented in DSS)							please choose: only expressing my subjective opinion
1.3	The abovementioned development of DSS will result in an increased number of DSS users (you can put down the % of influence this increase will have on individual functionalities as compared to 2012 in the "notes" column)							please choose: only expressing my subjective opinion

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Fig. 1. Queries on DSS development and user needs

In addition, respondents could self-assess the certainty of their replies on a 5-value Likert scale. This uncertainty was processed as triangular fuzzy numbers [3]. The initial analysis of responses is shown in Fig. 2. The first stage involved grouping the synonymous concepts provided by independent respondents with each other. Next, eleven main application areas of DSS were identified. The ones analyzed in Fig. 2 are: finance, business, education and HR, medicine and health care, production, and logistics. The other six that include security and e-government, are analyzed separately. The concepts are ordered from less specific to more specific, from left to right. Four cells on the right side of each box (ordered vertically for the five main concepts, and horizontally for all others) contain the occurrences of each concept (in %) in the base year (2015), the current year (2020), and the forecasting horizons 2025 and 2030 among all concepts mentioned for that year. Some of them are blank, which means that the percentages are not statistically valid.

The above characteristics of DSS application areas formed the basis in establishing a dynamic relevance ranking for the period 2020-2030. The greatest development of DSS will occur in healthcare, accounting for approximately 20% of all responses, while their relative relevance in business management will significantly decrease during the entire forecasting period. The current epidemic situation introduces anxiety about the future, which causes a significantly increased interest in epidemic management shown at level 2 in Fig. 2. However, a high standard deviation made these results statistically insignificant unless a clustering of responses was applied, yielding two scenarios with considerably different mean yearly demand growth (2,04% vs. 12,4%) for this field. This may be explained by the existence of two groups of respondents with distinct attitudes to the pandemic.

Further analysis aimed to link the application areas with tools and functionalities in a matrix storing relative importance of each technology (rows) to particular application areas or functionalities (cols). Henceforth, products, services, technologies, and market data submitted by industrial partners served as a basis for calculating each company's profile alignment with foresight results. Finally, these assessments are used in technological audits for IS/DSS companies within a current (2020-2023) ERDF-financed project.

4. Discussion and Conclusions

The above results are merely a sample of reported DSS foresight outcomes. The FSS tools are also capable of handling complex professional user requirements and consumer preference models concerning other intelligent software. They can be applied as inputs to technology and market models concerning education, health care services, media, and information markets. These provide clues to intelligent technology developers about future demand. Taken together with the responses' analyses to other surveys concerning relevant software development tools [12] for AILP, eScience, and DSS [13], the characteristics of technological processes from the developer's point of view could be retrieved and later used to build strategic technology development plans, according to the roadmapping scheme [2], [15].

Specifically, a foresight technique merging a morphological matrix [1] with cross-impact analysis, points to the need for an extended DevOps process for developing, updating, and operating the DSS, namely, a need for a broad involvement of end-users in Next-Release generation [5] during the system lifetime. This observation results from a strict interrelation between user preference retrieval and modelling with the DSS that also depends on the way that the user-DSS interaction process is designed and actually conducted. Another relevant issue is the impact of IS/AI trends on intellectual production capacity, and creativity [17]. Moreover, it turns out that recommender systems [10], typically used in e-commerce, can potentially be deployed in other classes of IS. The IS foresight outcomes can also provide R&D and educational institutions some feedback on the most likely directions of development and demand for AI professionals, as well as inform authorities and other interested parties on potential threats and disruptive changes that may be caused by irresponsible implementation of AI technologies.

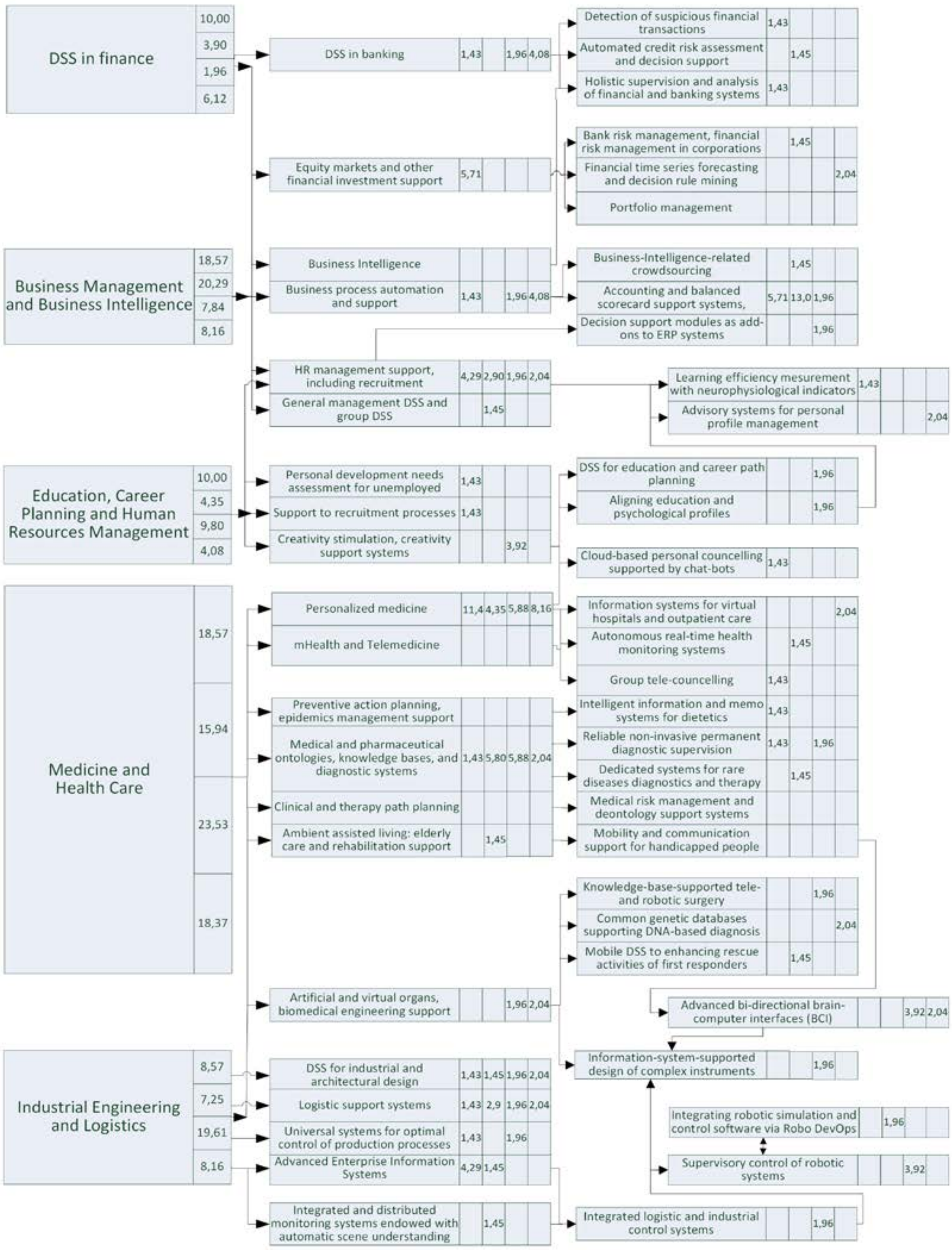

Fig. 2. The concept analysis of Delphi responses on DSS application areas, development and user needs

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