MULTIPARADIGM SOFTWARE TOOL FOR TECHNOLOGY FORESIGHT

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Abstract **- The technology foresight process seeks to identify technologies that will be key to national and/or regional economic development in the longer term, and to make recommendations to address the investment opportunities and other challenges associated with these technologies. International experience demonstrates that technology foresight is neither simple, nor is it unproblematic. As such, most international experts have come to agree that it is likely to be most successful as a continuous process rather than a one-off task. To make the technology foresight exercise simpler, cheaper, less problematic and inherently continuous, we have decided to support it by a software toolkit. This software also represents an effective platform for harmonising various foresight methodologies into a consistent composite. It enables a holistic foresight exercise, based on both panel activities (scenarios, recommendations, policy proposals, etc.) and a large scale "via-net" Delphi survey.**

INTRODUCTION

Technology foresight is presented as a set of methods to foster collaboration in multidisciplinary analyses of long-term scientific and socio-economic developments in order to identify technologies which may have future economic and/or a broader societal significance. This type of knowledge is crucial in making national priorities for allocating resources to research, industrial development and education - in both public and private contexts. Given the strong background in technology transfer to developing countries at the ICS-UNIDO, we have decided to undertake the development of a software package supporting technology foresight exercises, and also representing a valuable tool for increasing the chance that less developed countries undertake this resource consuming exercise, crucial for more effectively exploiting their potential.

Our multiparadigm software toolkit, comprising the three main (BATEV, DEBATER, CyberDELPHI) and a few auxiliary tools, enables a holistic forecasting exercise, combining some good aspects of various foresight paradigms based on both panel activities (scenarios, recommendations, policy proposals, etc.) and a large scale "via-net" Delphi survey. The combination of multiple paradigms supplies a firm foundation for addressing complex technology foresight problems more objectively. Following a brain-storming process (assisted by BATEV technology repository, and DEBATER intelligent decision support system for technology assessment) in which potential future opportunities for scientific and technological advances are identified, panels engage in an extensive and collaborative consultation process, using the CyberDELPI survey software.

The CyberDELPHI implementation is very useful in reducing the time required to evaluate the experts' responses and also helps to encourage the experts to give as much detail as possible.

This reduces considerably the resources needed to implement a traditional Delphi study (e.g. time and money), and could also yield better results. Not only could the survey be done by computerized Internet accessible questionnaire, but a software program could serve as a surrogate mediator and facilitator, or provide a decision support to human mediator. Here, the technology of Intelligent Group Decision Support Systems is utilized, which further adds to the innovative nature of our Foresight exercise. The final results of the CyberDELPHI sequence are forecasts, measures of expert disagreement and summaries of critical argument related to each issue.

The chief shortcoming of the Delphi method arose precisely out of the inevitability of reaching consensus views, since they were based on the opinions of a broad range of scientists. Earlier applications of Delphi were aimed at building a consensus but more recently it has been recognised that the reasons for dissent given by those who do not subscribe to the consensus are also worthy of note. Therefore, where the divergence is big, it could be wise not to try to reach consensus at any cost, but to exercise another very popular foresight technique, i.e. scenario development, in the areas of greatest disagreement, since scenarios could bring coherent pictures of alternative futures. As the biggest divergence in experts' opinions are expected in the areas containing elements of surprise or novelty in possible future directions, good forecasting in this areas demands creativity, insight and intuition of experts, the elements that could best be captured using the scenario development foresight technique. Scenarios encompass qualitative perspectives and the potential for sharp discontinuities and sometimes paradoxical conditions and options, that other techniques exclude. Critical to a good scenario development is the exact identification of these critical uncertainties, representing possible discontinuities, or step changes, which could have a major impact on the sector. The scenario could also display the interactions among several trends and events in order to provide an holistic picture of the future and depict a situation in a way readily understandable by the non-specialist in the subject area. Therefore, we have left the option open for panels to include scenario development into multiparadigm technology foresight exercise supported by our software toolkit.

FORESIGHT METHODOLOGY

Prior to designing our software support, we have undertaken an extensive analysis of available forecasting methodologies, comparing their respective advantages and disadvantages, and frequency of application in exercises already undertaken and published. In general, as a technology moves from the early stages of laboratory development to widespread acceptance in the marketplace, the forecasting methodologies that are most appropriate move from qualitative to quantitative techniques. Since technological forecasting is employed to predict long-term technological developments, the methods utilized are generally qualitative. Listed below is a subset of a wide variety of methods that have been developed to foresee technological developments:

- Trend Extrapolation,
- Historical Analogy,
- Delphi Survey,
- Critical Technologies,
- Expert panels,
- Scenario Development,
- Roadmaps,

- Cross-Impact Analysis,
- Group Decision Support Systems.

The detailed description of the above methodologies could be found in Ayers (1969), Ascher (1978), Amara and Salinik (1972), Martino (1983), Schwartz et al. (1982). Apart from well established techniques mentioned above, a variety of other methods used to conduct foresight exercises have been subjected to critical scrutiny in the 1990s, and there is a widespread view that the economic, institutional and cultural context of different countries should influence the choice between approaches. For example, countries of interest to ICS-UNIDO, mostly belonging to the under-developed and developing group, weak in industry but rich in natural resources, need to contemplate a different kind of future than would be the case in a major economy like Japan with a strong industrial base, limited natural resources and developed high technology.

Also, attention must be given to the likely social benefits (and drawbacks) of new technologies, and not just their impact on industry and the economy. A good technology foresight strategy should actively integrate different social values and objectives, and involve all potentially affected social participants (representatives from non-governmental organisations, consumers, etc. in addition to experts from industry or government). The key to successful foresight involves an appreciation of an holistic environment in which technology operates and consists of social, political, economic, environmental, technological and competitive forces.

Having assessed strengths and weaknesses associated with various approaches to technology foresight, we have concluded that whatever methodology is chosen (or even if the integrative route is taken, combining some good aspects of various techniques), it is essential nowadays to take advantage of emerging information technologies, which could significantly simplify the technology foresight process and reduce its cost accordingly. We have therefore opted for the creation of an original multiperspective, integrative approach, supported by a powerful, Internet-based, software toolkit.

We have assumed a rather flexible and generic structure for the technology foresight process. We envisage the foresight panels bringing together knowledge and expertise from all three operational legs (government, academia and industry), to be at the core of the Foresight process. To ensure that the expert panelists are aware of the full range of technology options available to them, the tool set offers both a repository of technologies (BATEV) and a decision support system to assist in the assessment process (DEBATER).

Panels would explore from a broad perspective, the forces of change in the country/region, and the role that science and technology can play. The BATEV repository will bring together all necessary information about available technological options and provide mechanisms so that expert panelists can broaden and share their knowledge and understanding of mature and emerging technological opportunities, in order to evaluate:

- existing global and local/regional scientific and technological strengths and resources;
- evolving global and local/regional socio-economic and environmental needs, threats, and challenges for science and technology;
- key future needs and opportunities which rely on, or could be significantly affected by, scientific developments and
- comparative advantages, and weaknesses;

The recognition and adoption of potentially promising technologies can be supported through technology foresight exercises in which a systematic analysis is made of how emerging technologies contribute to industrial competitiveness and societal change. On the other hand, uncritical deployment of new technologies may lead to controversial and adverse impacts. Thus, it is crucial to assess how technologies are likely to impact various stakeholders, in order to ensure that their eventual use does not violate widely held values. Therefore, in order to complement technical considerations with an assessment of economic, social, and environmental impacts, as well as regulatory issues, we have made available to the expert panelists, a decision support system for holistic technology assessment (DEBATER).

As the "panel only" technique would have widely recognized disadvantages ("one-off" basis, results biased by the opinion of panelists, etc.), our suggestion is to organise panels in order to reach consensus on the structure of the questionnaire and topics to be covered in each sector, and then undertake much wider consultations using an Internet-based Delphi Survey (facilitated by the CyberDELPHI software tool from our toolkit). With such a tool, a wide base of experts from academia, government and industry could be consulted easily, and results fused and integrated using computerised Mediator/Facilitator, implemented using a Group Decision Support Paradigm. As a result, a new revised questionnaire would be posted on the network for the second round of consultations using the same wide expert base.

The results of Delphi are presented on the second round of Sectoral/Thematic Panels, which would search for the causes of disagreement. The chief shortcoming of the Delphi method arose precisely out of the inevitability of reaching consensus views, since they were based on the opinions of a broad range of scientists. Earlier applications of Delphi were aimed at building a consensus but more recently it has been recognised that the reasons for dissent given by those who do not subscribe to the consensus are also worthy of note. Therefore, where the divergence is big, it could be wise not to try to reach consensus at any cost, but to exercise another very popular Foresight technique, i.e. scenario development, in the areas of greatest disagreement, since scenarios could bring coherent pictures of alternative futures. As the biggest divergence in experts' opinions are expected in the areas containing elements of surprise or novelty in possible future directions, good forecasting in this areas demands creativity, insight and intuition of experts, the elements that could best be captured using the scenario development foresight technique. Scenarios encompass qualitative perspectives and the potential for sharp discontinuities and sometimes paradoxical conditions and options, that other techniques exclude. Critical to a good scenario development is the exact identification of these critical uncertainties, representing possible discontinuities, or step changes, which could have a major impact on the sector. As stated in the literature (Martino 1983), the scenario could also display the interactions among several trends and events in order to provide an holistic picture of the future and depict a situation in a way readily understandable by the non-specialist in the subject area. Therefore, we have left the option open for panels to include scenario development into multiparadigm technology foresight exercise supported by our software toolset.

TOOLSET FUNCTIONALITY

To present the expert panelists with a full range of available mature and innovative technologies, among which to chose those whose future is worth investigating, the ICS-UNIDO is developing an Internet-accessible repository of the **B**est **A**vailable **T**echnologies, **E**conomically **V**iable (BATEV). This rich and up-to-date technology repository, could be used independently from the technology foresight exercise, for some technology transfer, dissemination and training, awareness raising and other purposes. Technologies from the candidate list are selected for inclusion into the BATEV repository if they meet one or more of the following criteria:

- Good technical performance
- Maturity
- System expansion possibility and upgrade reliability
- Economic prosperity
- Market success
- Competitiveness
- Job creation and economic growth
- Improved cost efficiency
- Credible environmental performance, etc.

The goal of BATEV is to ensure that all sorts of stakeholders, including expert panelists in the technology foresight exercise, could get acquainted with the full-range of technology options, available to them to assess, either by themselves or using DEBATER, and characterize their applicability in the future society, and their role in national and/or regional development.

Technology assessment and technology foresight can be viewed as interactive processes which seek to produce an enhanced understanding of new technologies and their consequences. In technology assessment, the emphasis is often on a comparative analysis of benefits and the impacts that may be caused by a chosen technology, including its negative and harmful consequences. Technology foresight, on the other hand, can be viewed as an attempt to look into the longer-term future for the purpose of identifying strategic research areas and technologies that are likely to produce the greatest economic and social benefit. Both technology assessment and technology foresight can be supported by the application of methodologies such as decision support systems and multi-criteria analysis. The need to bring in elements from technology assessment to the technology foresight exercise has been increasingly recognised. Therefore we have decided to include our decision support system for technology assessment into the toolkit.

The decision support system is called **DEBATE^{2}R** (**D**ecision-aid for **E**valuation of **B**est **A**vailable **T**echnologies, **E**conomically and **E**nvironmentally **R**eputable). The name (although naturally derived from the first letters of its functionality descriptors), suggests that the automated decision support system only takes part in the debate on the issue, i.e. the evaluation and selection of the best available technology, taking into account its technical performance, economical viability, and environmental soundness. The final decision, of course, is up to the human decisionmaker.

This way we will also fight the fear and prejudice concerning artificial intelligence and decision support systems, being thought of as a potential threat to human decisionmakers, leaving them unemployed. The DEBATER will debate the issue with its users and make its recommendation (together with the ranked alternatives). Its users will be allowed to be interactively involved with the decisionmaking process, to change the decision elements or even the decision as a whole (preferring one of the ranked alternatives suggested by DEBATER). It offers technology evaluation, comparative analysis of technology alternatives and selection of the best available, environmentally and economically viable technology and provides expert panelists with well balanced recommendations based on their own choice of criteria and their relative measures of importance.

DEBATER factors human experts' experience into decisionmaking in a fashion that is friendly as well as powerful and that gives its users confidence in its recommendation. Owing to its intrinsic intelligence and richness of the underlying databases, it can be far more useful and reliable than any information and recommendation source otherwise available to the panelists. It processes and distills the experience of many experts and applies it to the particular problem at hand without bias.

Since DEBATER is interactive (not fully automated), the user actively interferes the decision process, not only to obtain explanations for the system recommendations, but also to choose the most feasible alternative according to some subjective criteria and intuition (if needed) or to change some partial decision elements. The main reason to keep the system open for the user is the unstructured nature of the technology selection process and frequent need for human intuition and judgement, not easily described in any artificial intelligence formalism. Humans possess unique knowledge and inside information that is not easy to include in any quantitative method.

With DEBATER, expert panelists will be able to make rational choices among technology alternatives by using their specific choice of measures and criteria, among those included in the technology overview. Detailed description of the DEBATER software is outside the scope of this paper and could be found in S. Vranes and F. Pizzio (2000).

Having assessed the available mature and emerging technologies, expert panelists compile Web questionnaires for wider expert consultations. Both editing and processing of questionnaires are facilitated by CyberDELPHI tool from our software toolkit.

The Delphi survey is a group facilitation technique which seeks the opinions of experts through a series of structured questionnaires, anonymously completed by the experts. The responses from each questionnaire are fed back in summarised form to panelists as part of the process. The advantages of a Delphi survey are that it allows all opinions to be considered in a non-adversarial manner, and gathers expert opinion without the need to physically bring them together.

In our generic structure of the technology foresight exercise, the purpose of the survey was to allow the panels of experts to consult widely in the business and science and technology communities, to assist in achievement of commitment to results and consensus on developments, and to inform these communities about the major issues being addressed in the exercise and how their peers assess those issues.

Our computerisation of the Delphi process, CyberDELPHI, is an Internet-based interviewing package, meant to be used as a consultative instrument for the Panels, with the topics and issues raised being generated by the Panels and reflecting directly their concerns. It also provides a tool for communication. It increases efficiency and lowers the cost in comparison with standard paper-and-pencil postal Delphi surveys. It enables the creation and editing of a CyberDELPHI questionnaire which are easy to use even for novice computer users. The tool also automates the process of collating and analysing the completed questionnaires, i.e. producing summary statistics and histograms of results. It creates an archive, containing the results of all the iterations. This archive can be browsed and annotated to produce a summary of the experts opinions, and thus can be used as a basis for the design of the questions in the next iteration.

As well as the most obvious function of gathering opinions for the Panels, the CyberDelphi also aims to involve large numbers of experts who would otherwise be excluded, and hence to widen significantly the constituency of participants feeling ownership of the results and a consequent commitment to their implementation. The fourth objective relates to dissemination. Receipt of the questions gives the respondents early feedback on the topics deemed to be of interest by their peers on the Panels. The second round form extends this feedback by providing early access to the views of all respondents on these topics. Experts are thus able to benchmark and re-appraise their own views.

SOFTWARE ARCHITECTURE

Our software toolkit should be Internet-accessible, which imposes several requirements on the system architecture itself. It should support the wide distribution and the different technical knowledge of users, possibly a large number of concurrent accesses to the system, different types of Web browsers owned by users, etc. On the other hand, survey results collating and processing (CyberDELPHI), not to mention multicriteria analysis and symbolic processing (DEBATER) are always connected with the exhaustive usage of memory and computing resources. These requirements make a three-tier architecture, with a thin client, the most convenient for the realization of such a software system (see Figure 1.).

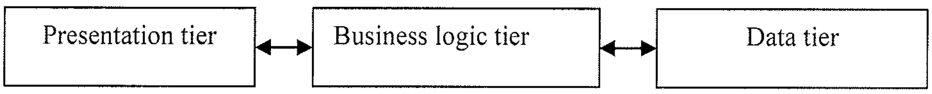

Figure 1. Three tier architecture

In our architecture, a Web browser with Web server presentation modules represents the presentation tier; databases and other information sources and archives represent the data tier; and application modules that perform the information processing represent the business logic tier. The physical structure that supports this software architecture includes:

- client computers with Web browsers on the client side,
- Web servers that generates presentation forms and dialogs (questionnaires in CyberDelphi, technological options and indicators in BATEV and DEBATER),
- application servers that perform business logic services (results processing and facilitation, decisionmaking), and
- databases (results archives, technology repositories) and other information sources (library of predefined questionnaires) on the server side (see Figure 2).

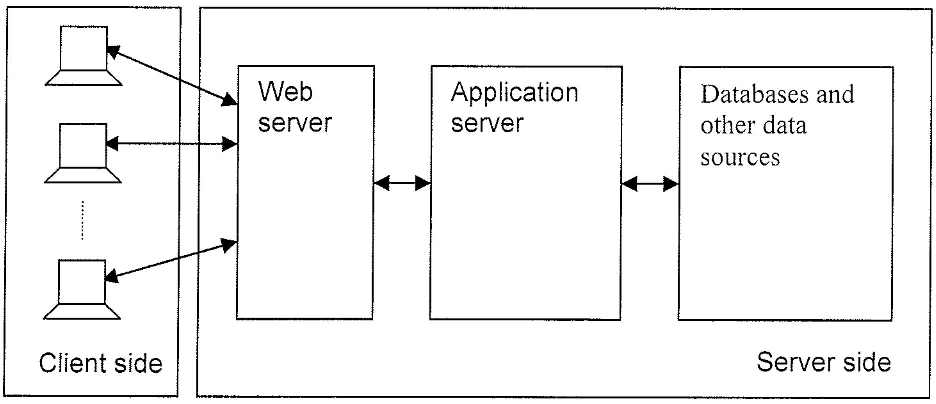

Figure 2. Physical system architecture

This architecture presentation logic (that resides on the Web server), is physically separated from the business logic, thus enabling efficient information processing on the application server, that can be specialized for its purpose (survey results processing, technology assessment, data retrieval, etc.)

The entire architecture is based on the use of classes and protocols provided by a Java 2 platform. Plain HTTP (HyperText Transfer Protocol) is used for communication between the Web browser and Web server. Communication between the Web server and application server is realized through the Java Remote Method Invocation (RMI) protocol, while access to the database is performed by using the Java DataBase Connectivity (JDBC) protocol (see Figure 3).

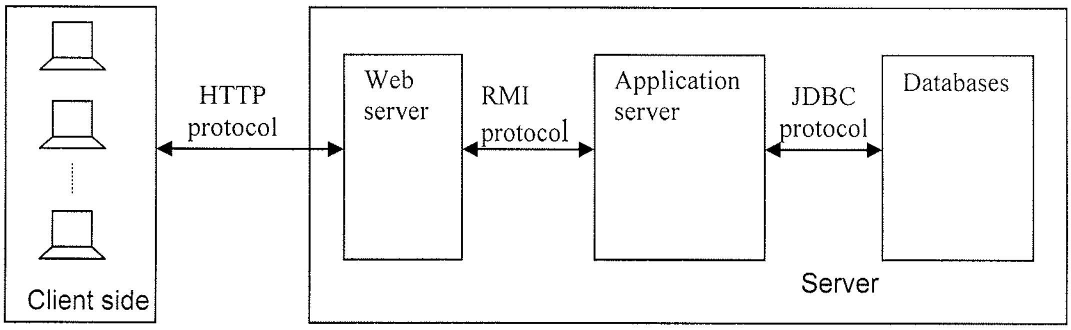

Figure 3. Communication protocol

The presentation tier consists of the Web browser that resides on the user's machine, and the Web server software modules on the server side. The role of the presentation tier is to provide users interaction with the application such as input to the application, and presentation of the results of pre-existing information processing. The only software that a client requires is the Web browser, and the entire user interface is created on the server side and then sent to the client browser. The user accesses the HTML pages dynamically created by servlets, which practically represent the client application on the server side. Servlets are Java objects that reside on the Web server, and are capable of creating dynamic HTML forms and processing them. The entire application, in this approach, still resides on the server side, which enables easy maintenance and updates. The user communicates with the server through standard HTML forms. Since there is no direct access to the application server (servlets access the application server), the system is much more secure. The drawbacks of this approach lies in the fact that the HTTP protocol is stateless, so the context of the user's work can not be saved in the application (or the applet) on the client side. It has to be preserved on the server side. The approach with servlets has been chosen, mainly because of the application server security and the low request for resources on the client side (see Figure 4).

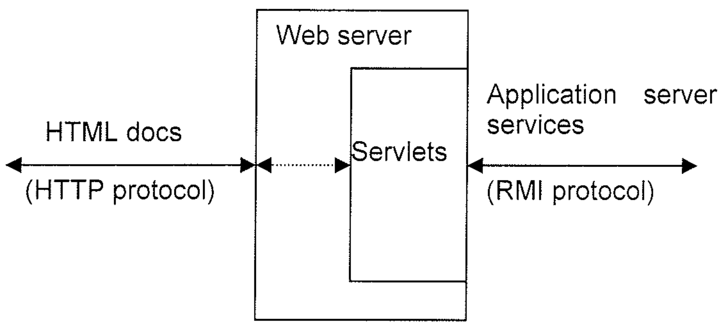

Figure 4. Web server

Servlets call the application server services during the processing of submitted HTML forms, and the creation of new forms. This is done through the remote calls of application server functions, performed by using RMI protocol. For this, the reference to the application server functions interface should be obtained by servlets. This should be done during the servlet initialization.

Business logic tier

The business logic tier consists of the software modules that perform the application logic (results collating and processing in CyberDELPHI, transaction processing in BATEV, and multicriteria analysis and symbolic processing in DEBATER). In our case this tier consists of three layers: the RMI interface implementation layer, the application logic layer and the transaction management layer (see Figure 5). The RMI interface implementation layer implements the remote functions, accessed by the servlets and other client applications, the application logic layer performs the main information processing, and the transaction management layer provides safe concurrent access to the data sources. The business logic tier is physically implemented as a multithreaded server application module that resides on the application server.

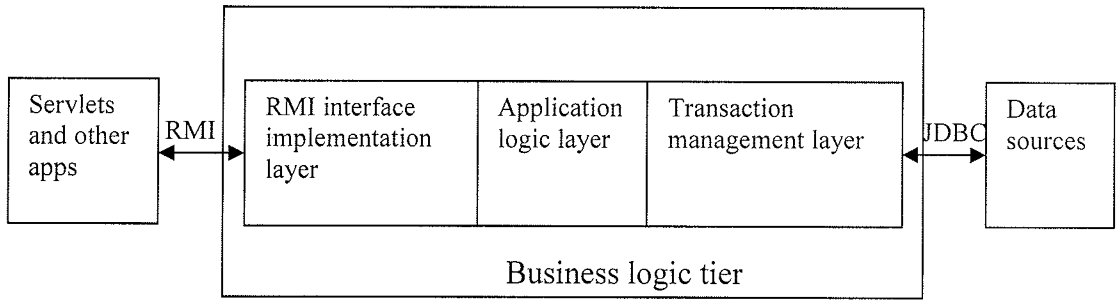

Figure 5. Business logic tier

RMI interface implementation layer

The role of the RMI interface implementation is to receive the data (in the form of remote function arguments) from the remote source and to pass this data in the appropriate form to the application logic layer, which performs the real data processing.

There are different types of users of network-based application: regular Internet users, local users and administrators (application administrators, database administrators, Web administrators, data providers, etc.). All these users access the server application in the transparent manner, by using RMI remote function calls (see figure 6). They could be Internet, Intranet or local users.

Application logic layer

The application logic layer performs the data processing, and represents the heart of the architecture. This layer is agent-based, as described in Knapik (1998) and Weiss (1999). The specialized autonomous software units – agents perform the entire data processing in this layer. They are working cooperatively to achieve the goal that none of them separately can reach.

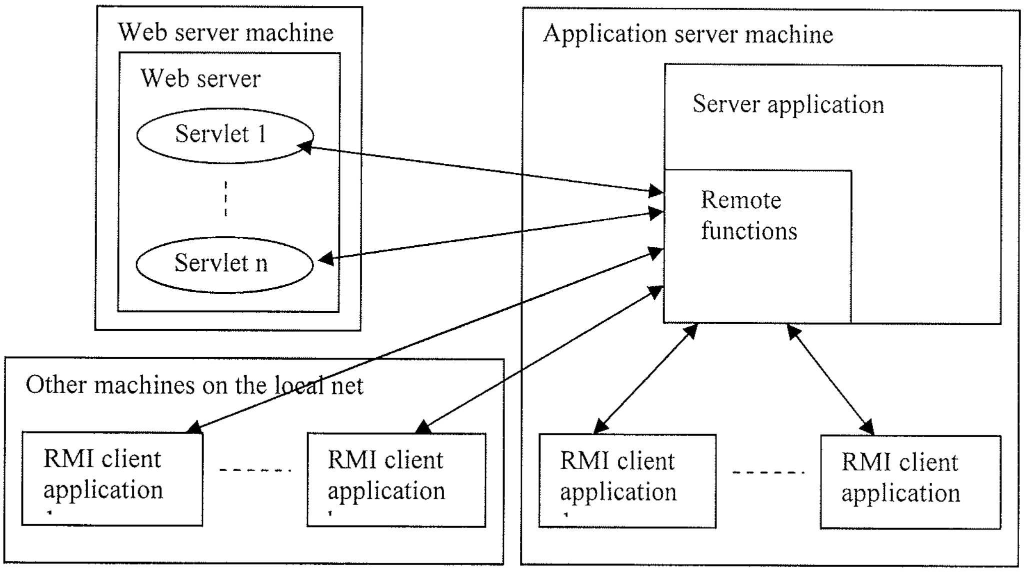

Figure 6. Users of the application server services

The agents communicate by exchanging messages. Messages have a layout similar to the form defined by the KQML (Knowledge Query and Manipulation Language) standard (Labrou, 1997). The messages between the agents are exchanged through the object that represents the medium that delivers the messages from one agent to another.

Agents are advertising to and unadvertising from the message medium object. Advertised agents are ready to receive messages and answer them if needed (like in the case of "ask-one" performative). When the agent sends the message to another one, the message is posted to the message medium. Message medium extracts the name of the receiving agent from the message, searches through the list of advertised agents for the receiver of the message, and when it finds the receiver it delivers the message. If there is more then one receiving agent, the medium object itself decides where it should deliver the message

Since the RMI interface implementation layer should deliver the data from the remote procedure call to the agents in this multiagent environment, the only way to communicate with the agent society is through the agent messaging system. The object that implements RMI interface advertises itself like all other agents. When it receives the remote procedure call, it should put the data received as the call argument in the newly created message, and send it to the appropriate agent. The agent to whom the message should be delivered is defined by the context of the data passed by servlet. Instead of analyzing the message context, the RMI object should send the message to the agent specialized for this purpose. This agent should deliver the message to the appropriate receiver, and return the answer to the RMI object.

CONCLUSIONS

Given the strong background in techmology transfer to developing countries at the ICS-UNIDO, we have decided to develop a software package supporting technology foresight exercises, which represents a valuable tool for increasing the chance that less developed countries undertake this resource consuming exercise, crucial for more effectively exploiting their potential. Our software toolset (BATEV, DEBATER, CyberDELPHI) enables a multiparadigm foresight exercise, combining some good aspects of various foresight techniques based on both panel activities (scenarios, recommendations, policy proposals, etc.) and a large scale "via-net" Delphi survey. Following a brain-storming process (assisted by the BATEV technology repository, and DEBATER decision support system) in which potential future opportunities for scientific and technological advances were identified, panels engage in an extensive consultative process, using the CyberDELPHI Internet survey software.

The combination of multiple paradigms supplies a firm foundation for addressing complex technology foresight problems more objectively. The expert panelists are assisted a great deal by the decision tool called DEBATER, that helps them assess future impact and benefits of both mature and innovative technologies, taking into account holistic environment and all relevant criteria (technical, economical, environmental, social, etc.) simultaneously.

The toolset also helps its users to overcome some limitations of conventional methodologies. For instance, "paper and pencil" Delphis are usually limited by the "top-down/bottom-up" dichotomy, rather than allowing more complete parallel entry to any aspect of the problem. In the computerized environment, using the CyberDELPHI software tool, individuals could be free to tackle any aspect of the problem according to personal preferences.

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