

Information technology support for the knowledge and social processes of innovation management

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Abstract

While the management of innovation is the most knowledge-intensive organizational process, its information technology support has received only fragmented attention. The majority of systems proposed are either aiming at augmenting individual creativity and productivity, or at increasing the productivity of communication among the actors involved. In this paper, building on the view of innovation as a process of consecutive problems resolution, we present an information systems framework that aims at integrating different actors' perspectives and tools across different activities, by explicitly addressing the knowledge and social dynamics of the whole process. The framework is based on a systemic problem-knowledge representation scheme and an evolutionary problem-resolution methodology that supports the innovation process in its entirety, enabling the gradual 'breeding' of innovation concept(s). After reviewing the relevant literature, we present the structure, functionality and use of *Knowledge Breeder*, a web-based software system that implements this methodology through a structured dialogue and a formal argumentation scheme. By means of a use case we show how this system can support the innovation process effectively.

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1. Introduction

Innovation is a process where knowledgeable and creative people and organizations frame problems and select, integrate, and augment information to create understandings and answers (Teece, 2001). Hamel emphasizes the role of information technology as an enabler not only of product or process innovation, but also of what he calls business concept innovation (Hamel, 2002). Admittedly, organized information cannot substitute tacit knowledge, understanding and learning, which are the most important resources of the innovation process, but it can significantly enhance them by helping to fill existing knowledge gaps. Organisational knowledge gaps are the result of the discrepancy between the knowledge an organisation has and the knowledge it needs for the solution of specific

problems, including innovation and product development (Debackere, 2004). In filling these gaps, the role of information technology is not only to organise data into useful information, but also to support the transformation of information into organisational knowledge. Even more, since innovation is a social process involving diverse actors, there is a demanding necessity for information and communications technologies (ICTs) to support the knowledge flows among the relevant actors and artefacts, in a way that enhances the creation of new knowledge. As knowledge and information flows are the key determinants of successful innovation and new product development processes (Brown and Eisenhardt, 1995; Tidd et al., 1997), their technology support can augment their efficiency, effectiveness and, consequently, their role as input-based competences and sources of competitive advantage (Zhang and Lado, 2001).

A closer examination of innovation as an organisational process, from both the knowledge-based view of the firm and through the lens of the social dynamics of organizational decision-making, sketches the necessity for

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information systems that explicitly address the interplay between social and knowledge processes, which holistically form an evolving complex system (Harkema and Baets, 2001; Ottosson and Bjork, 2004). On the other hand, from the information technology point of view, it is clear that, in addition to database and internet solutions for technology and market scanning, tools for exploring and assessing the context (e.g. experimentation tools) and finalising the form of innovation concepts (e.g. engineering design tools), the above processes require the support of collaboration technology that allows a rich expression and discussion of ideas/proposals under specific problem contexts. Furthermore, this technology should support the efficient storage and retrieval of codified knowledge, allow experimentation with ideas and potential solutions, as well as providing support for argumentation and conflict resolution. Systems implementing these technologies in isolation, as well as integrated frameworks, being mainly focused on the engineering design phase, have been proposed and used in actual organizational settings (Divitini et al., 2000; Eloranta et al., 2001; Christensen et al., 2003; Sethi et al., 2003). Their principal aim, however, has been to increase individual productivity and creativity or/and to increase the productivity of communication of codified knowledge between the actors involved. The innovation process as an intellectual and social process of consecutive problems resolution has not been addressed sufficiently in its entirety.

By adopting a processualist view of information management, in this paper we initially discuss the appropriateness of Knowledge Management Systems (KMS) and related information technology as vehicles for enhancing the innovation process. We then present an integrating information systems framework that can be used to support the knowledge and social routines and processes in innovation management. The proposed framework does not bring a variety of people and tools together in an ad hoc basis or through a project-management context, but rather through a problem-resolution-as-an-intellectual process logic, which relies on a collaborative model building methodology and a systemic modelling formalism. As activities/routines in all the phases of the innovation process constitute problem resolution tasks (Leonard and Sensiper, 2003), models are used to represent personal and organisational cognitive schemata (knowledge) of what the problem(s) is/are and what its/their solution should be. The social and knowledge dynamics of innovation are supported by the co-evolution of models with respect to shared knowledge. A formal argumentation language is used to facilitate actor interaction.

2. Innovation as a knowledge management process

For the design of an information system to support innovation, it is necessary to understand innovation as a core business process. The holding view of the structure

and function of this process with respect to organization has evolved over the years, from the purely sequential linear models of ‘technology push’ (from R&D to the market) and ‘market pull’ (from market to R&D) to a coupling and matching process where interaction is the critical element (Rothwell, 1992). Current models see innovation as a continuous multi-actor process that requires high levels of integration at both the inter- and intra-firm levels. Obviously, from both the knowledge and social dynamics perspectives, information technology in the form of collaboration-supporting systems can enhance systemic integration and networking along these axes, support flexible and customized response to internal and external signals, as well as coordinate and integrate different knowledge sources.

During the development of innovative concepts, individuals from diverse functions, as well as potential users, are involved in different activities, or routines, which can be broadly organized into four phases, not necessarily being executed in a linear fashion (they are usually iterated). In the scanning phase, ideas on exploiting internal or external opportunities are placed for consideration. Discussion, filtering and structuring for decision making takes place through formal and informal organizational routines and procedures. In the strategy development phase that follows, the organization is concerned with what to do with the innovation concepts developed. Three inputs to the phase are placed for consideration: the outputs of the previous phase, the internal technological assessment and the fit of the emerged innovation concept with the overall business. Once the strategy for the qualified concept has been decided, in the next phase the resources required for its implementation are considered. Dilemmas such as make or buy have to be resolved. Finally, in the implementation phase, the actual development activities (design, prototyping, testing, etc.) are carried out (Tidd et al., 1997). All phases contain decision-making routines, which involve individuals with diverse backgrounds, knowledge, skills and cognitive spheres. In the majority of cases, relevant decision making is a participative process that begins with an initial idea (proposal or solution), continues with the exploration of alternative ideas, before it is focused on the exploitation of the most appropriate (and most promising) of them (Schwartz, 2003; Leonard and Sensiper, 2003). This interplay between social and knowledge processes results in the emergence of groups-within-groups. Apparently promising ideas attract a critical mass of supporters, which argue in their favour. Other groups attract less support and more opinions against their ideas. In this manner, as social processes result in the formation of groups, knowledge is combined and clustered around specific ideas, concepts, solutions or views. In the more normative perspective of viewing knowledge as belief in cause–effect relationships that describe an issue, organisational (group) knowledge corresponds to shared belief in such a system (Sanchez and Heene, 2004). Consequently, the principal challenge in

the management of the innovation process is to provide the means, in the form of knowledge representation schemes and social and organisational norms, for accommodating different, and frequently conflicting, individual knowledge sources into a single perspective.

The importance of the involvement of diverse knowledge sources in innovative product and process development has been greatly emphasized in the literature. It has been shown that the use of cross-functional teams with diverse occupational and intellectual backgrounds increases the likelihood of combining knowledge in novel ways (Nonaka and Takeuchi, 1995). In such teams, the amount and variety of information available to members is increased, enabling the proposal and consequent evaluation of different alternatives from a number of different perspectives (Brown and Eisenhardt, 1995). Moreover, in the modern multi-site enterprise, these teams are not only functionally diverse, but also spatially. Users and partners from remote places may need to participate in the innovation process. These further emphasize the instrumental role of IT as enabler for the formation of virtual teams to execute the innovation process (Qureshi, 2000; Kessler, 2003; Rad and Levin, 2003).

3. Information technology for collaboration and knowledge management in the innovation process

The innovation process in general, and new product development in more particular, has been served by a number of diverse technologies under the umbrella of ICTs. At the individual participant, or designer, level, creativity enhancement and idea representation and processing systems have been developed and frequently used. In this category, one can include experimentation technologies such as simulation and rapid prototyping, which are employed at different phases of the innovation process with varying degree of detail (Schrage, 2000; Thomke, 2003). Early phases of the process are associated with conceptual models of the product (or service, or issue) and its relation to their environment of use, whereas later with the physical characteristics and its engineering design parameters (parametric design).

Building on the understanding of the innovation process as a collaborative process, ICT technologies to facilitate communication between individual actors and their tools have been proposed and implemented, principally for the engineering design phase (Christensen et al., 2003; Sethi et al., 2003, www.cocreate.com, www.matrixone.com). The main objective has been to facilitate and to increase the productivity of exchange of design artefacts through a shared workspace. Some of the tools in this category incorporate features for the automatic propagation of design changes across different tools and representations. With the direct involvement of potential users, the adoption of such systems in the new product development process has been

instrumental, as far as the outcome of this phase is concerned (Hillebrand and Biemans, 2004). However, as they do not address the knowledge and social processes of innovation explicitly, they offer marginal support to the core of the innovation process. They are concerned with the *whats* and *hows*, rather than the knowledge creating *whys* of innovation activities.

Computerised KMS, on the other hand, are intended at providing a corporate memory, that is, an explicit, disembodied persistent representation of the knowledge and information in an organisation (a sort of knowledge base) (Heijst et al., 1997) and mechanisms that improve the sharing and dissemination of knowledge by facilitating interaction and collaboration (Taylor, 2004). There is a widely accepted view that while computer-based KMS are not efficient for effective knowledge sharing, they are nevertheless essential components in most organisational settings (Ruggles, 1998; McDermott, 1999; Gold et al., 2001). In the search for the characteristics of a computer-based KMS for the innovation process, and leaving aside knowledge storage technology which is fairly standardised, one has to look at collaboration technology beyond the time/space framework (Turban and Aronson, 2001). Having in mind the innovation process, collaboration technology can be classified into idea-exchange systems, work-process oriented systems, and problem-solving oriented system. In the first category belong systems that implement forums for the exchange of messages and attached documents through an appropriate infrastructure. Web-based conferencing systems such as AltaVista Forum Center, Open Meeting and NetForum belong to this category. These systems exploit the platform-independent communication framework of the Web, as well as its associated facilities, for data representation, transmission and access. They usually provide the means for discussion structuring, while the more sophisticated allow for sharing of documents, on-line calendars, embedded e-mail and chat tools, etc. Discussion is structured through a variety of links, such as simple responses or different comment types (e.g. *qualify*, *agree*, *example* in Open Meeting) to a previous message. This category of systems meets fully the requirements that are related to the spatial and temporal distances between members of a team. However, they merely provide any means to support individual and collective intellectual processes, neither implement a strategy for achieving shared understanding.

The second category includes systems for the controlled execution of routine sequences of work tasks through a shared work space of available tools and associated artefacts. They usually have project management, versioning and, sometimes, automatic modification features (Medina-Mora et al., 1992; Bose, 2003). Tools in this category are also close to the communications infrastructure and include Microsoft's Active Directory and its associated products, as well as more innovation-specific tools such as

the tools for the NPD phase referred above, which directly use these capabilities.

The third class, which is closer to the requirements of a KMS for supporting the innovation process, takes into account explicitly the intellectual processes of idea creation, decision-making, negotiation and argumentation. Since the early 1980s, under the banner of Group Decision Support Systems (GDSS), a number of such systems have been proposed and used (Conklin and Begeman, 1987; Smolensky et al., 1987; Fischer et al., 1989; Streitz et al., 1989; Lee, 1990; Shum et al., 1993; van Reijswoud et al., 1999). Common characteristic of these systems, but also the differentiation point among them, is a modelling formalism used to represent a problem. Modelling formalisms have been evolved over the years from purely numerical, used with methodologies such as the multi-criteria analysis, to more qualitative, such as cause and effect relationships. As a consequence, the decision-making process supported moved towards a conceptual model building exercise, on which the use of electronic systems is varying from a purely facilitated session (e.g. Vennix, 1996) to the automatic translation of qualitative models into system dynamics models (Dean et al., 2000; Howick et al., 2004).

Taking into account the dynamics of the innovation process, three criticisms can be made to the above methodologies and tools:

1. They do not provide expressive languages which allow the simple representation of complete rationales and arguments.
2. They exhibit an ‘urgency’ for the integration of the different perspectives into a single solution-concept, from the very early stages of the problem resolution process.
3. They poorly support consistency throughout consecutive problem resolution through meta-modelling.

The proposed methodology and the system that implements it aim at overcoming these drawbacks.

4. The G-MoBSA methodology and the Knowledge Breeder environment

4.1. General features and process

Group Model Building by Selection and Argumentation (G-MoBSA) is essentially a systemic problem/issue resolution methodology enriched with formal argumentation to provide the interaction mechanisms needed for structuring the necessary knowledge. The actors involved in the innovation process can provide their own complete interpretation of the issue in the form of cause–effect models. Models are the result of individual sense-making of the organization and its environment, which includes facets of the outcomes of previous instances in the innovation process.

All models representing the problem space are subject to discussion, argumentation, and eventually, modification by other actors. The validity of each model is subject to argumentation at various levels (as a whole, in its constituent elements, or in specific relationships between its elements).

Conflict resolution is through formal argumentation rules. In addition to providing the space for collaborative model creation, argumentation is a social construction methodology that provides structure and outcome to dialoguing, thus placing group interaction at the centre of knowledge acquisition (Metcalf, 2002). The defensibility of each model is determined as a guide its validity, which leads to its eventual collective selection or rejection. On the basis of his/her perception of the issue, each team member can construct and propose a model of the problem and its solution using the language of the problem–solution modelling formalism. As the participant has access to the whole set of models proposed, he/she may adjust his/her mental models and contribute to the construction of models accordingly. Both the model per se (completeness) and its defensibility (fact-supported argumentation) can change a participant’s perception. At the same time, the participant seeks facts/information to further support his/her proposed model, which may have the indirect effect of reviewing his/her own perception and knowledge base. The same modification processes take place with respect to the mental models of the other participants. As a result, mental models (beliefs) are converging around specific models and some of the models attract more attention concentrating the argumentation on them. Normally, the model that is best supported by facts and attracts the favourable views of the community is finally selected. In this way, G-MoBSA aligns the model building process with the social dynamics of the team involved in the resolution of the issue.

In G-MoBSA, every group member participates in four distinct activities with respect to the model: construction of a model, presentation and understanding of a model, critique to a model, and intervention on a model. Model construction is synonymous with the externalisation phase of knowledge construction (Nonaka and Takeuchi, 1995). The model construction activity involves an intensive interaction between the modeller’s world and its knowledge base in one hand, and the context on the other. It is a process of knowledge transformation from tacit to more codified forms. In trying to codify, pieces of knowledge are critically reviewed, associated and receive new meaning. Overall, the development activity leads a participant to organise his/her knowledge base and arguments in a more complete and consistent way. At the same time, indirectly defines the space of possibilities that he/she sees and proposes for action. Model presentation and understanding also result in the re-organisation of a participant’s knowledge base. In trying to interpret another participant’s model, someone either deletes elements and associations from its own

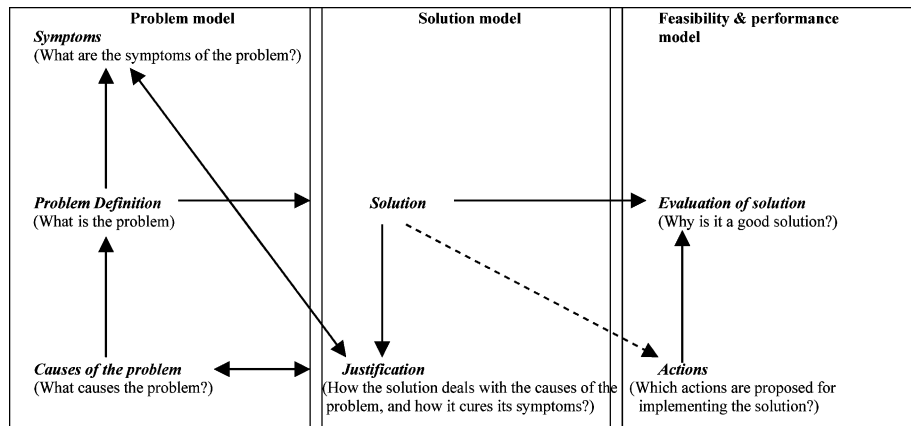


Fig. 1. The G-MoBSA modelling formalism.

knowledge, or strengthens his/her views by associating different facts and different (new) meanings. This is a more personal and tacit process (knowledge internalisation) compared to the critique and intervention activities that involve, as in model construction, externalisation of knowledge.

4.2. The G-MoBSA modelling formalism

Fig. 1 shows the basic structure of the modelling formalism used in G-MoBSA. It consists of seven parts: problem definition, causes of the problem, symptoms, solution, justification of the solution with respect to the roots of the problem and its symptoms, evaluation of solution, and proposed actions.

In the problem definition, a participant's perception of what constitutes the problem is asserted. The causes-of-the-problem section provides participants with a template to answer the question 'why this is the problem'. The reasons that cause the problem can be described in a hierarchical cause–effect manner. Logical connections (e.g. 'A AND B cause C') can be inserted and are used for argumentation and conflict resolution. In the symptoms section, the results of the existence of the problem (again, as they are seen through the specific participant's eyes) are defined in the same hierarchical cause–effect manner. In the solution proposal clause, the proposed solution is briefly defined, while justification provides the proponent with the means to argue why the proposed solution cures the causes of the problem and, directly or indirectly, eliminates its symptoms. Attached to the proposed solution is its evaluation, which allows the proponent to argue why the proposed solution is a feasible and effective one. Finally, the proponent can insert a set of proposed actions to justify his/her evaluation with respect to them.

This modelling formalism provides the means for expressing complete cognitive schemata of *what* constitutes the problem, *why* this is the problem, and *how* the proposed solution cures it in the most suitable way for the company.

4.3. The argumentation system

Although different argumentation systems can be used, the current implementation of G-MoBSA relies on the logical propedeutic of the Erlangen school (van Eemeren et al., 1996). In our methodology, complete arguments are represented by means of simple statements related by logical connectives (operators). The logical connectives used are confined to: AND (conjunction), OR (disjunction), IF...THEN (implication) and NOT (negation). The argumentation schema provides the rules for conducting the dialogue among participants and resolving conflicts, i.e. it indicates which argument or clause holds and which is defeated.

More specifically, the starting rule indicates that the participant who asserts a complete model (thesis) is the proponent who starts the dialogue. Participants that defend elements of the model are the opponents, while participants that support statement are the supporters. In a specific dialogue instance, a supporter may become proponent as a different participant challenges his/her argument. There is no predefined priority rule as far as the assertion of positions is concerned. The general dialogue rule indicates that, at any instance, a proponent can attack one of the statements put forward by an opponent or defend himself/herself against an opponent's attack. The opponent, in turn, can attack the statement made by the proponent in a preceding move, or defend himself/herself against the proponent's attack in the preceding move.

The structure of the models implies that the winning rules focus on combined statements (elementary statements connected by logical connectives), rather than on simple assertions. Consequently, ultimate victory results from the successful defence of elementary statements on which argumentation has been exercised. The specific winning rules are:

- If a node in the model is supported by two or more statements connected with the AND operator, then an opponent may argue against this statement by attacking

the supporting elements individually. If the proponent of the model can defend the attacks on the supporting statements, the model is considered to be defensible (holds). Otherwise, this part of the model, including any reasoning based on it, is in doubt.

- If an argument is composed of two statements connected with an OR operator, then an opponent may attack the whole statement at once. The defender has two chances to defend the argument, corresponding to the two constituent parts of it (three if the argument constitutes of three statements, and so on). Depending on the outcome of the conflict (defended or not fully defended argument), the supported argument may be declared as defensible or in doubt.
- If a participant attacks an argument based on the implication relation, then he/she is obliged to provide either a different cause or a different effect/implication. This provides the main reason for supplying a different model of the problem and/or solution. The defender may defend the cause or the result of the implication.
- Finally, if the proponent of a negative thesis is challenged, the opponent has to assert that the argument holds. If the proponent succeeds in defending the negation, the argument is considered as defensible. Otherwise, it is in doubt.

4.4. Information technology support—the *Knowledge Breeder* environment

In the G-MoBSA methodology, the different stages of the model building and selection process are not executed in a linear mode, but every time a member of the community interacts with the shared modelling space, the threat of the execution of the methodology moves there. This is facilitated through *Knowledge Breeder*, an IS framework operating on the web (Fig. 2). The kernel of *Knowledge Breeder* is the model base that stores the models under discussion, and models of terminated discussions. Any form of electronic information artefact, as well as direct links to individual tools can be attached to the model (documents, drawings, hypertext links, etc.)

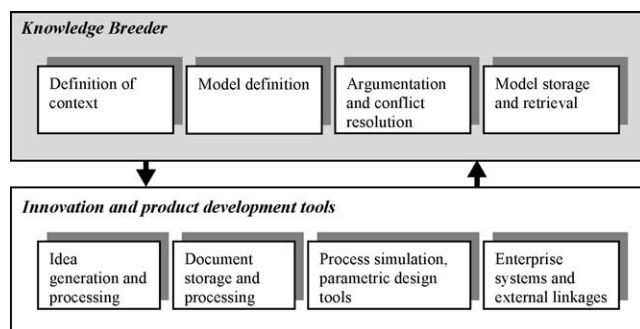


Fig. 2. The basic structure of *Knowledge Breeder*.

and transferred across different actors. Models are selected and stored hierarchically, on the basis of a meta-model of the issues addressed or to be addressed (context definition). Users can upload the current issues under consideration in which they wish to be involved, see the current state of the dialogue and contribute accordingly. Then, they can move in to other issues through the navigating meta-model. By taking into account the structure of the model, the arguments placed and the argumentation rules, the inference engine of the tool determines, at any instance in the resolution process, the defensibility of each model.

The interface of *Knowledge Breeder* is in hyper-textual form with menus associated to the features provided and buttons serving folding and unfolding purposes. This results in easier asynchronous interaction since complex graphs are more difficult to be understood by participants involved in the discussion asynchronously. This was observed during the evaluation phase in a software company that develops simulation systems. The sample session described in the following section refers to the same company.

5. Managing the innovation process with *Knowledge Breeder*

In this section, we briefly present how *Knowledge Breeder* can be used in a specific issue resolution within the innovation process. It is clear that the G-MoBSA methodology supports a process that simultaneously considers both the external and the internal environment of the firm from diverse perspectives.

In the sample session presented, managers of a simulation software development company are engaged in a discussion, in an early phase of the innovation process, over the evaluation of a new product concept which is based on a novel technology. Fig. 3 shows the problem–solution model proposed by the company’s CTO. In his view, the company’s limited growth (upper-level symptom) which follows from embracing ‘Cost-leadership strategies’ (lower level symptom) is the result of the technology currently used in the products of the company. In more analytical terms, all competitors use the same interface and simulation-engine technology, and being limited by their technological base, they offer the same range of services. As a solution to this problem of technological homogeneity, he proposes the adoption of Agent Based Simulation (ABAS) technology. He justifies his proposal by arguing that it is a new scarce technology, which can provide the basis for differentiation in services (justification). In addition, he connects the potential success of the adoption of this technology to the publicity given to complexity science, with which the proposed technology is related. Furthermore, he supports his claim by informing the other stakeholders in the process that by adopting this technology the company will be able to use the existing distribution channels, to exploit intelligent

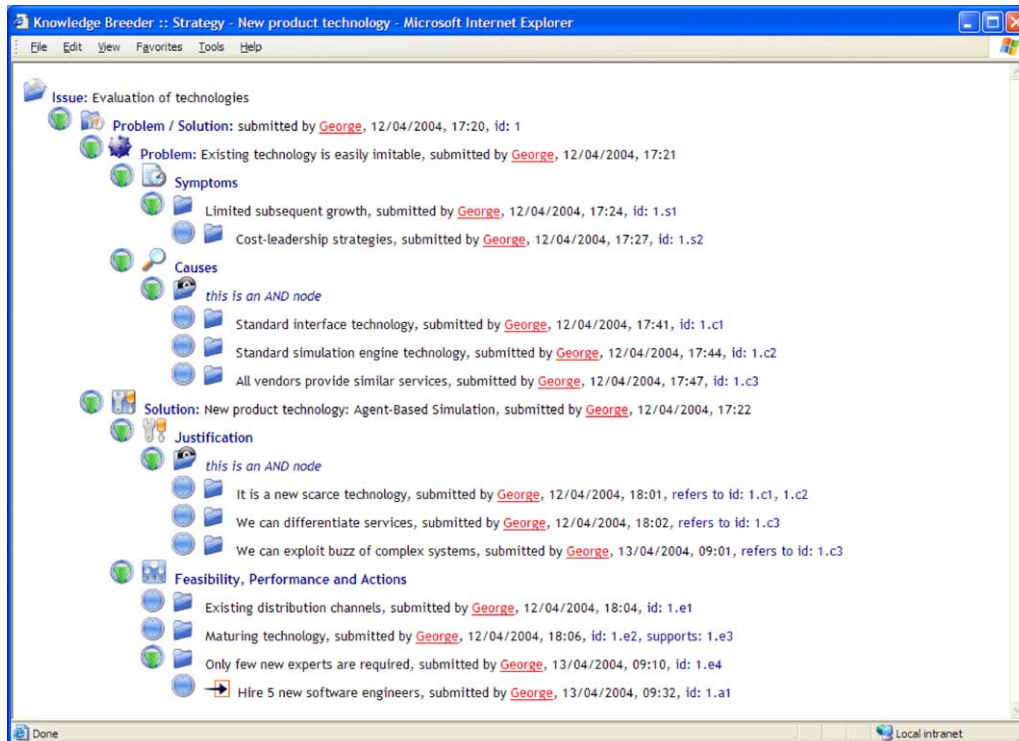


Fig. 3. A complete model of an issue in the innovation process.

agents technology and to use the existing technical human resources (estimates that only a few (proposes 5) new experts are required).

This model, as presented in Fig. 3, provides the individual knowledge of CTO as his belief in cause–effect relationships that govern the issue of technology selection. Upon selecting the appropriate context/problem, *Knowledge Breeder* provides to each participant interested in placing a model for consideration, a template structured on the basis of the G-MoBSA modelling formalism. By selecting the specific model section, the system prompts for inputting model elements/statements. In turn, by selecting a statement, the user can input elements that further support it. By clicking on each element, a proponent can provide additional information in a free-text form or through links to web pages and documents. The structure of this form is shown in Fig. 4 for the item ‘We can exploit buzz of complex systems’.

Fig. 5 shows another instance of the same model, which includes additional arguments placed during the collective problem resolution process. One can observe the agreeing and re-enforcing argument of the Services Manager with respect to the homogeneity in services (‘All competitors can offer training, support hotline etc.’) and the attacking argumentation of the Senior Project Manager that indirectly prompts participants to his own argumentation/model

(consider:2). This participant questions the validity of the model by arguing that the firm does not possess the complementary assets needed for differentiating its services (business—not simulation—consulting experience and capabilities for marketing such services). At this stage,

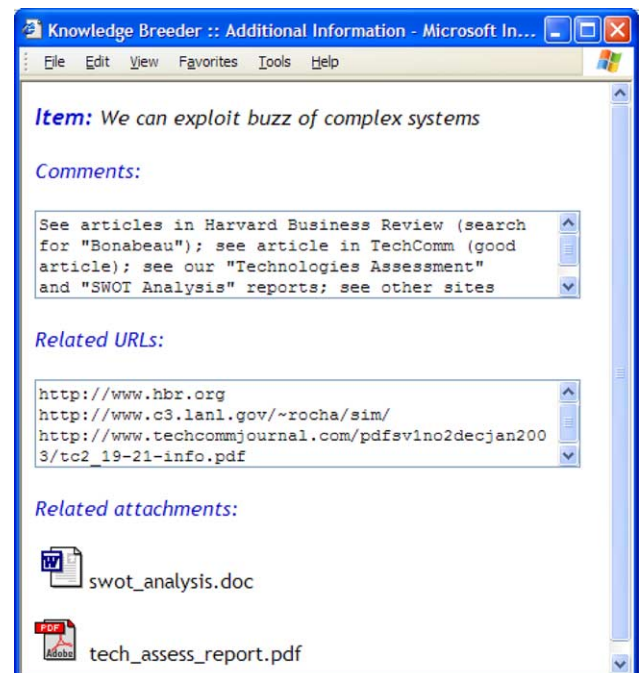


Fig. 4. Item description and external references (extract of model of Fig. 3).

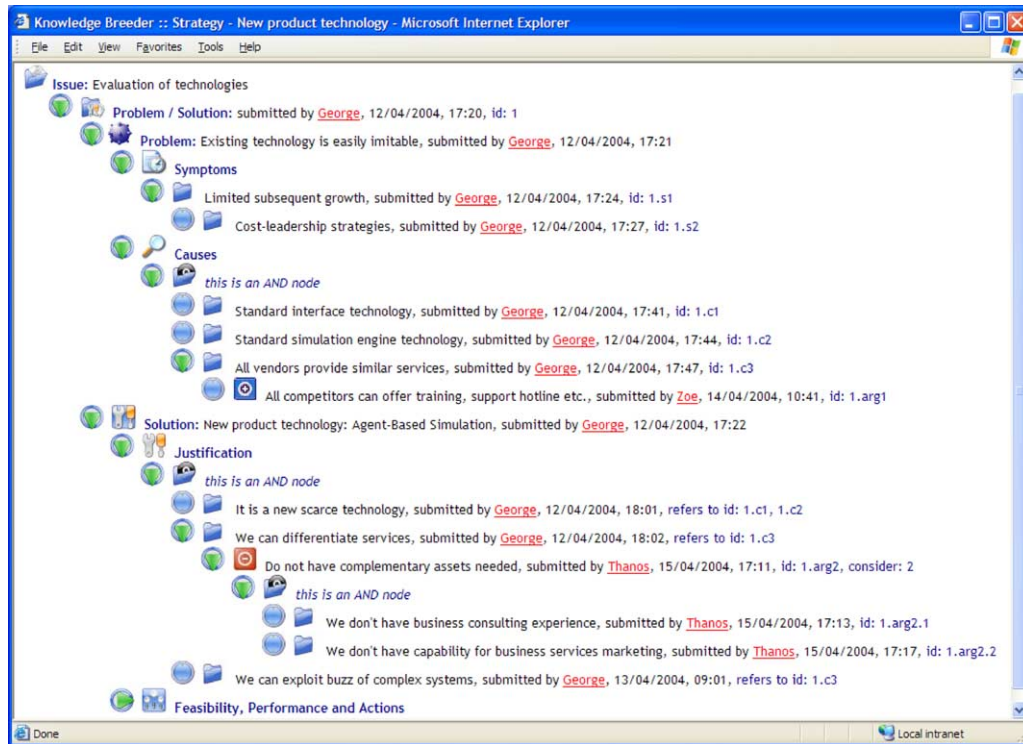


Fig. 5. The initial model with additional argumentation.

since the proposed solution of the CTO is supported by statements under an AND connective, using the predefined conflict resolution rules, the system infers that the whole model is in doubt. The result of the insertion of an argument under an OR connective would have been different, as the parts of the model rooted in both operands of an OR relation may be considered independently. To defend the model, the proponent (or any other participant) has to defy the arguments of the Senior Project Manager by providing his/her opposition. Alternatively, the argumentation of

the Senior Project Manager may result in the development team (including the proponent of the first model) to concentrate on his model, or on other participants' models that deal with the same issue.

Positions asserted as models are evaluated with respect to their defensibility (validity in relation to the shared understanding of the team). The defensibility of each model is a qualitative and indicative measure summarized at any instance in the discussion in the form presented in Fig. 6 (after 10 rounds of argumentation). There, participants can

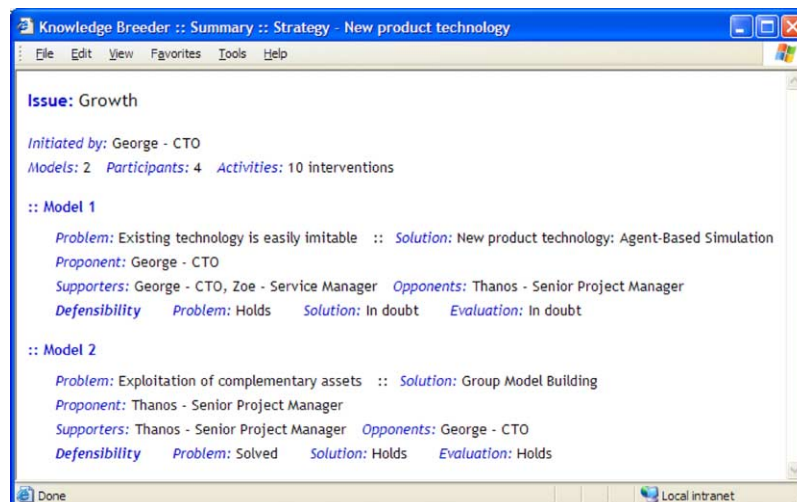


Fig. 6. Summary information for the evolving problem resolution.

see which models, parts of models, or arguments are in doubt. By clicking on specific parts of the models, participants can see details of the argumentation, as well as more detailed statistics, e.g. the number of attacks on an argument, the number of successful defences, replies, etc. Of course, it is up to the participants' own judgment to make the final selection.

6. Conclusions

Innovation is a task that depends upon the individual members and the collective knowledge of the organisation. As a process, at each stage, it involves problem identification, problem solving, and prediction and anticipation. Social interaction is the most essential element of the process, and the role of information technology is to structure it in a manner that while, on the one hand, encourages divergence of perspectives, on the other, convergence to valuable outcomes is attained.

Towards this end, in this paper, we have presented how the collaborative problem-solving methodology G-MoBSA can be used to support the innovation process. In G-MoBSA, innovation is viewed as a breeding process where the innovative concept co-evolves with the knowledge of the actors involved in the process. The core of the methodology consists of a problem–solution modelling formalism for providing consistent views of the issue and a formal argumentation schema for conducting the dialogue among development team members.

We have demonstrated the use of *Knowledge Breeder*, the IS framework that implements the methodology, through a sample instance of a particular phase of the innovation process in a software development company that develops add-ons for modelling and simulation environments.

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