HOMEBOTS: Intelligent Decentralized Services for Energy Management

Hans Akkermans [‡] **Fredrik Ygge** [§¶] **Rune Gustavsson** [¶]

[‡]AKMC Knowledge Management
and University of Twente
Information Systems Department INF/IS
P.O. Box 217, NL-7500 AE Enschede, The Netherlands
E-mail: akkerman@cs.utwente.nl, akkermans@ecn.nl

[§]EnerSearch AB
Carl Gustafs väg 1, S-205 09 Malmö, Sweden
World Wide Web: http://www.enersearch.se

[¶]SIKT, University of Karlskrona/Ronneby
Villa Wega, Brunnsparken, S-372 36 Ronneby, Sweden
E-mail: { Fredrik.Ygge, Rune.Gustavsson }@ide.hk-r.se

Fourth International Symposium on the
Management of Industrial and Corporate Knowledge ISMICK'96
Rotterdam, The Netherlands, 21– 22 October 1996

Abstract

The deregulation of the European energy market, combined with emerging advanced capabilities of information technology, provides strategic opportunities for new knowledge-oriented services on the power grid. HOMEBOTS is the name we have coined for one of these innovative services: decentralized power load management at the customer side, automatically carried out by a 'society' of interactive household, industrial and utility equipment. They act as independent intelligent agents that communicate and negotiate in a computational market economy. The knowledge and competence aspects of this application are discussed, using an improved version of task analysis according to the COMMONKADS knowledge methodology. Illustrated by simulation results, we indicate how customer knowledge can be mobilized to achieve joint goals of cost and energy savings. General implications for knowledge creation and its management are discussed.

1 Introduction

Due to the deregulation of the European energy market, the electric utility industry is in a transition from being a regulated and rather monopolistic power generation industry, to a business operating in a dynamic and competitive free market environment. For the utility industry a new business paradigm is therefore emerging. The usual business of generating, distributing and billing customers for kWh — essentially a pure product-oriented delivery concept— is being transformed into offering different kinds of new value-adding customer services (Figure 1). These vary from automated metering and billing at-a-distance, advice on optimized energy use, tailored rates and contracts, to home automation, home energy management and demand-side management at the customer's premises. This paradigm shift will open up new opportunities, but will also necessitate new ways of thinking for most utilities, as it requires a two-way communication between the utility and the customer. Here, utilities are facing the fact that proper utilization of information and knowledge is a key component in a competitive market. The traditional power distribution net must be supplemented with an information network allowing for extensive two-way communication between customers and the utility, in order to provide the new services as mentioned above. Figure 1 concisely characterizes the main aspects of this transition in the energy market. Information technologies (IT) will be crucial enablers here.

Figure 1: Paradigm shift in energy utilities due to the new information society: from a pure product delivery concept to two-way customer-oriented services.

In this paper, we will discuss one of these new knowledge-oriented services based on two-way communication with the customer: decentralized power load management. In section 2 we will outline the general service concept, and in section 3 we sketch a business task analysis. Section 4 describes the implementation and shows some results of simulating the new business process. Section 5 then discusses the general knowledge management aspects and implications following from our case.

2 New Intelligent and Distributed Services: The 'HOMEBOTS' Concept

In one of the episodes of *Star Trek: The Next Generation* the following incident occurs. After some big argument, one of the crew members runs to a machine in the wall of the *Enterprise* and commands: "Give me a hamburger, now!" The machine appears to be some combination of an intelligent refrigerator with an automated cook annex quick-service counter. After the request, the machine makes some unintelligible sounds as if it is puzzled, and then asks the crew member to explain what is meant by a 'hamburger'. When it has heard her explanation, it says: "I am terribly sorry, but I have been designed to serve you good and healthy food — so hamburgers are outside of my competence!"

The time is not very far that this is no longer science fiction. Recent advances in IT have made it technologically and financially possible to equip many different types of nodes in the electrical network (including 230V and other substations, industrial loads and even household equipment) with significant communication (230V power grid, fiber optics, GSM, etc.) as well as computing capabilities of their own. In this way, nodes in the electrical network will obtain the capabilities to act as intelligent and interacting agents on behalf of the customer and the utility. There are quite a number of different advanced information technologies that jointly act as enablers here, such as: (i) cheap programmable chips that can be built in into many types of equipment; (ii) advanced telecommunications technology; (iii) knowledge and software engineering: object and knowledge technology and multi-agent systems; (iv) emerging facilities and standards for using the power grid (also) as an integrated information infrastructure.

In Sweden, a large project called ISES is now underway to perform research and develop new services based on these recent advances in IT. It is headed by EnerSearch AB — a joint venture of IBM Utility and Sydkraft AB— and is sponsored by ABB Network Partner, Electricité de France, IBM Utility, Preussen Elektra, Sydkraft AB, as well as by the County of Blekinge and the Municipality of Ronneby in the south of Sweden. One of the new service applications that are foreseen is that the electric network nodes themselves act as intelligent agents in order to take care of power load management. Such intelligent agents we call 'HOMEBOTS'. This load management would lead: (i) for the utility, to a better utilization of the power grid as a result of reduction of peak (valley) loads of the power net; and (ii) for the customer, to a minimization of the overall energy cost, while maintaining a specified (individual) comfort level.

This will provide the supplying utility with new opportunities for power load management and demand saving in the distribution grid. Better load management and demand saving has a significant impact on reducing and postponing investments by utility industries. At the same time, it is in the customer's interest, since it allows for cost reduction by taking advantage of tailored and more flexible tariffs and client contracts, for those customers who are willing to participate in load management actions.

The economic background and industrial relevance of this work lies in the fact that the energy market is undergoing a tremendous change in Sweden (deregulated as of 1 January 1996) as well as in most other European countries. The electric utility industry is in a transition from a regulated power production and delivery industry to an industry branch that has to operate in a dynamic and competitive free-market environment, forcing the utility companies to rethink and redesign their strategies. As depicted in Figure 1, the shift will be from being pure power suppliers to enterprises that offer a range of support services that are responsive to customer energy needs.

Within this general business context, the recent advances in IT offer a wide range of challenges and opportunities for competitive advantage. Technological breakthroughs in communication and computing are important enabling factors in the reshaping of business areas of the utility industry already now. And it is more than likely that their impact will further intensify for many years to come. Within the energy utilities, R&D in the fields of Distribution Automation (DA), Demand Side Management (DSM), Home Automation (HA) and Home Energy Management (HEM) are addressing issues and infrastructures to support future services in respective areas. (For more information on the utility background and the ISES project, see the EnerSearch WWW pages: http://www.enersearch.se).

Power load management is one out of a host of new customer support services in the future, and our HOMEBOTS concept aims to exploit one of the many opportunities that are created by the emerging IT and two-way communication capabilities on the power grid. The objective of the HOMEBOTS project, one of the subprojects of the ISES project, is to develop the *high-level software and knowledge methodology and technology* needed for the collaboration of intelligent-acting utility and customer equipment. Such a collaboration is to act as a *service society* of HOMEBOTS, where many individual equipment agents communicate and negotiate, in a free-market bidding like manner, to achieve energy and cost savings both for the utility and the customer.

We note that the HOMEBOTS application represents a specific (and certainly not the only conceivable or useful) approach to load management, both from a technology and a business point of view. It is positioned at the end of the utility's value chain. It is a customer-based and service-oriented approach to load balancing with two-way communication (instead of central and one-way control) between utility and customer as an essential prerequisite. So, if successful, it will bring along the introduction of new business processes within the utility that are radically different from current processes. Technologically speaking we are also far from traditional real-time control. Instead, we are dealing with a society of constrained but knowledgeable computational agents that operate in an open, dynamic, market-like environment with incomplete information. Rather than simply calculating needed figures, there is a strong judgmental aspect involved, since major tasks in the HOMEBOTS approach to load management are negotiation and assessment. So, the two important technological characteristics here are that we are dealing with (i) multi-agent systems and (ii) with knowledge-intensive processes.

The central technical problem that the HOMEBOTS project addresses is how high-level goals of consumers and suppliers can be achieved by a society of constrained (semi-)intelligent agents that have different views on and knowledge of their environment (Figure 2). This central problem of multiple agents in a consumer environment is characterized by the following features.

- The society of agents is open and dynamic: agents may enter into or disappear from

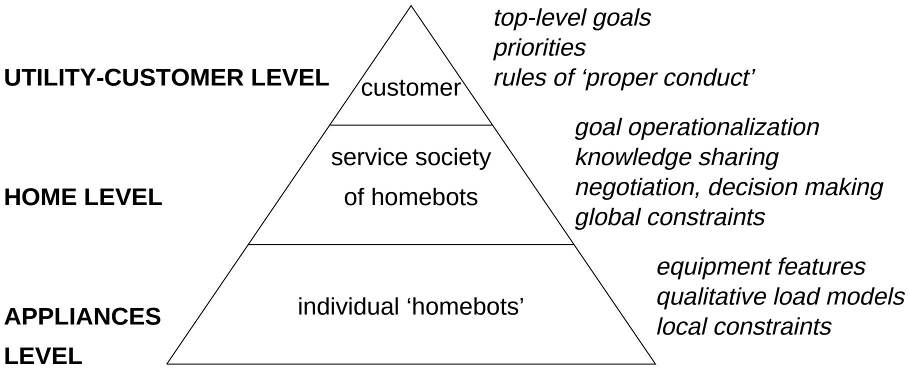

Figure 2: Multiple and heterogeneous agents in the HOMEBOTS society providing demand-saving home services in the power distribution grid.

the society.

- The human is part of the society because the high level goals of the consumer and the utility (comfort level, cost savings, optimal operations) should drive the behaviour of the HOMEBOTS.
- Each agent has incomplete knowledge of the system as a whole. The precise state of equipment is usually only locally known to the HOMEBOT that controls it.
- The agents in the society have to satisfy certain global and local constraints (e.g. on total power demand, safety constraints, technical operation regimes, etc.).
- At a local level HOMEBOTS can have conflicting goals and may compete for available resources. They also may have different views (in Artificial Intelligence one uses the beautiful term 'ontological commitments' for this) on the world surrounding them, posing problems of systems and services integration.

The general approach to solving these issues is to apply well established knowledge and object-oriented technology (COMMONKADS, OMT, etc.) in combination with multi-agent paradigms, and to link these to lower layers of commercially available communication technology (especially on the 230V power grid) and programmable microprocessor infrastructures (such as LonWorks). Thus, the key issue is how existing results from different fields are to be employed and integrated. Fields involved are information modelling and knowledge engineering/management (agent models), multi-agent systems (society architecture), distribution automation programming (in high-level languages), and lower-level communication protocols and hardware-oriented languages (DLMS, LonWorks Neuron-C). Our view here is that suitable results from these fields are currently available as separate components, but what is lacking now is the methodology to integrate them in the context of practical industrial applications.

3 Knowledge-Oriented Business Task Analysis

As pointed out, decentralized power load management services effectively imply the introduction of a new business process into the utility. There are several fields that are useful in providing an understanding what a business process or task is, and how it should be analyzed and conceptually modelled. First, there is now an extensive literature from the business administration area on, e.g., Business Process Reengineering and literature on knowledge as an enterprise asset (e.g. [1– 4]). Secondly, a lot of useful insights can be gained from Information and Knowledge Systems analysis (e.g. [5– 8]). The different fields tend to have their own perspective, however, resulting in different emphasis and methods.

3.1 Modelling a business task

The IT areas tend to take a more content-oriented or 'inside' view on processes. There are many approaches, but a global picture has emerged that it is useful to distinguish between implementation-oriented systems design, and analysis at a higher level, such that it is understandable by humans and that abstracts away from implementation details. The latter is usually called the conceptual or knowledge level. Another established aspect of this global picture is that tasks can be analyzed by means of what we will call a 'three-dimensional information model'. The three dimensions of analysis are: (i) a functional view telling what the input / output flows are connecting the various subtasks or subprocesses; (ii) a structural view specifying the (static) contents and structure of information objects that are handled in the process; and (iii) a dynamic view defining the temporal and control aspects — sequence, iteration, events, decision-making points — during the process. This 3D style of information modelling is for example reflected in the widespread use of, respectively, data-flow, object / entity-relationship, and state-transition modelling and diagramming techniques. Most IS approaches tend to focus on the technology side only and take the business aspects for granted, with the exception of James Martin's Information Engineering [5] and the CommonKADS knowledge methodology [8].

On the other hand, business administration work tends to take a more management-oriented, 'outside' view on processes. It stresses the strategic goals that should drive the process, the value that it creates, performance objectives and critical success factors, needed resources and capabilities in the organization. Methods for process content analysis (as employed particularly in BPR) are relatively high-level and simple compared to most IS areas, and the associated (re)design methodology is rather global.

It seems to us that both 'inside' and 'outside' perspectives are needed in analyzing and designing new business processes, services and supporting IT systems. If we then try to integrate these complementary perspectives into a balanced view on what a business task is, the following definition seems suitable. *A business process or task is a goal-oriented activity that:*

– *delivers desired outputs in a structured way,*
– *adds value to the organization,*

– *consumes resources,*
– *requires (and provides) competences,*
– *is carried out according to given performance criteria,*
– *by responsible and accountable agents.*

Accordingly, a task or process model will contain the following components:

3D information model: A model of the way in which the desired outputs are delivered, by providing an analysis along three dimensions:

1. *Functional submodel*: process decomposition into subtasks, their inputs and outputs, and the I/O flow connecting the subtasks into an overall 'process network'.
2. *Structural model*: a description of the information contents and structure of objects that are handled in the task, such as its input and output objects, in terms of entities and their relationships. This gives a 'repository of knowledge assets' relevant to the business process.
3. *Control/Dynamics model*: a description of the temporal order of and control over the subtasks, providing a picture of the triggering events, decision-making points and other knowledge about time aspects, needed in managing the process.

Agents: Who are the agents responsible for executing subtasks in the process? 'Agents' are to be understood here in a general sense as any actor capable to perform tasks, be they humans, IT systems, machines, or sources outside the organization. A significant aspect of business process innovation currently is to redesign the task distribution over agents, utilizing the emerging IT capabilities in the form of a new type of agents (by the way, this is why 'automation' is an inadequate and often misleading concept).

Competencies: What are the underlying competences required for properly carrying out the process? Conversely, given available competences, what kind of new processes do they enable? Knowledge management focusses on understanding and managing these competencies.

Resources: What are the resources, in terms of time, cost, etc., consumed in carrying out the process?

Added value: What is the value contribution of the process to the value chain of the business? The notion of value has become a key concept in enterprise modelling. Especially in knowledge-oriented services, it is increasingly pointed out that value creation is not only done by the company itself, but that suppliers and even customers can be co-producers of value. Power load management by HOMEBOTS are a case in point. A systems approach to the value creation aspects of the process will therefore become more and more essential.

Performance: Both task execution measures and methods must be specified in order to assess the performance of a process. Here, Total Quality Management (TQM) is an important source of ideas and practices. Quality metrics measure various aspects (cycle time, cost, first-pass yield, and so on) telling us whether tasks are performed according to set goals and target levels. Performance methods will in addition be often defined in a quality-driven process, informing us about the framework within or even how tasks are to be executed. This covers best practice guidelines, but also task features considering, for example, norms, regulations (e.g. safety and environmental laws), authority restrictions (e.g. can IT agents overrule human decisions, or do they only act in an advisory capacity?) and other constraints governing the agent's task execution.

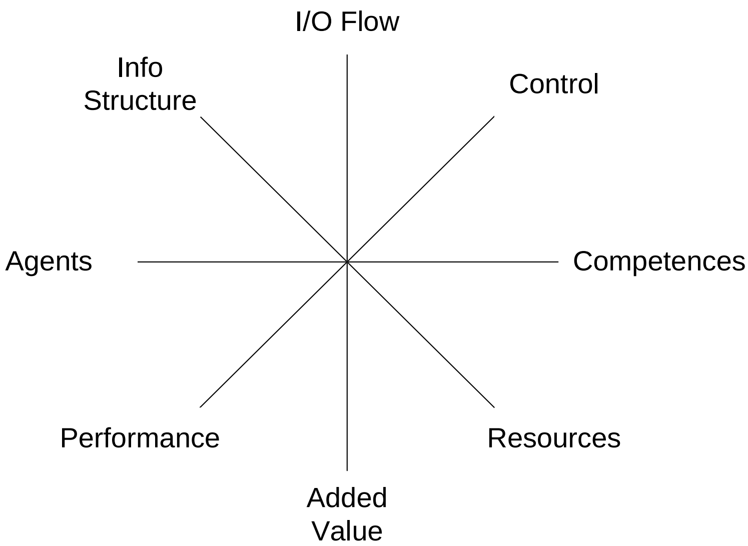

Figure 3: Modelling a business task.

Thus, a simple, yet comprehensive process analysis is possible according to the Task Model 'star' depicted in Figure 3.

3.2 Initial Homebots Task Analysis

Following the framework of the previous section, we give here a first-cut task model of load management by HOMEBOT agents.

Agents In the initial experiments we want to keep things as simple as possible. For a reasonable testbed we need the following agents:

1. One intelligent agent representing the utility. If we consider, say, a small residential area, this node will reside somewhere in the low-voltage grid, in a secondary substation (transformator) area supplying a collection of family homes.

2. For each customer, one or more agents acting as representative. Under each customer, we have a number of household appliances or industrial equipment: the HOMEBOTS.

As a testbed, think of a HOMEBOT society covering a group of single-family homes. A secondary substation serves about 50 family homes. Energy use by families is mainly heating and warm water, the rest is relatively simple base load. So we can imagine two types of HOMEBOTagents per customer: heaters and boilers. Even in this simple system, we have on the order of 100 agents, with a total energy consumption on the order of 200 kW. Thus, being able to do load management here is already a significant achievement.

3D Information Modelling An initial *functional model* can be arrived at by a breakdown of the top task of load management according to: (i) separation of subtasks of a different nature and (ii) separation of subtasks for which the responsibility rests with different agents. Looking at the nature of the task, load management by HOMEBOTS can be viewed as a cycle of *Assess-Negotiate-Monitor* subtasks. Each of these can be further split up. The simplest scheme for negotiations is a three-stage Announce-Bid-Award process. Assessment activities take place at the different steps in this process, but in addition they have varying reference points, particularly goals to be achieved, technical possibilities, and expected financial benefits. Assess and Negotiate are both knowledge-intensive tasks. The top-level I/O flow is pictured in Figure 4.

A good general starting point for a *structural model* is to list the input/output objects handled in the above task decomposition (the nouns being good indicators), consider them as entities and then work out their relationships. Of special interest are those entities that play the role of control parameters in the load management scenario. In our application, so-called *utility functions* — a concept borrowed from microeconomic market theory — are employed to summarize the needs and preferences of the utility and the customers (see further next section). They depend on a number of factors and parameters such as the load model, the current state of the load, the outside temperature, the expected price situation, substation constraints, and the required customer comfort level.

The *control dynamics* is driven by the negotiation procedure and associated communication actions. Conceptually, it is basically given by following the functional I/O flow sketched above. Furthermore, a mechanism to avoid or break deadlocks is that when things are not working properly, the situation of business as usual — no load management at all— prevails.

Competences Many of the needed underlying competencies follow from the above information model. For each type of agent we give a list of the major competences it must be endowed with.

For the individual HOMEBOTS acting on behalf of the customer:

- Knowledge about their own typical demand curve (say, over 24 hours).

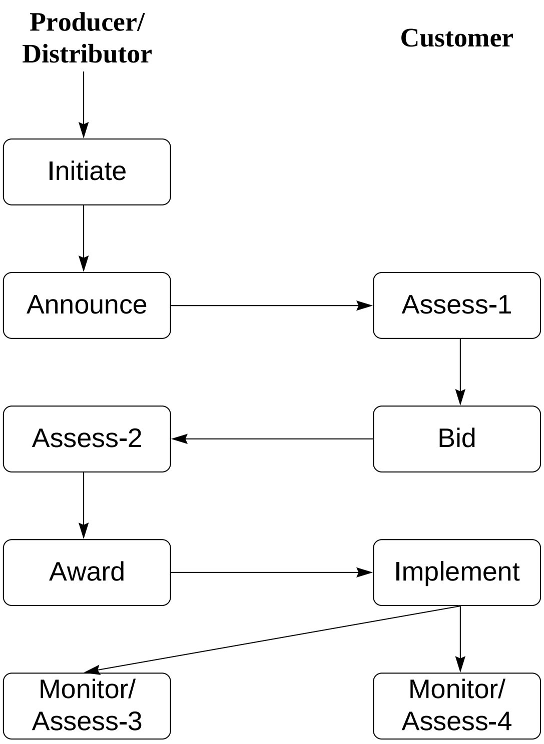

Figure 4: Top-level information flow in the HOMEBOTS load management task.

- Cost calculations for any given demand curve, and assessment of cost results with respect to the customer goals and constraints.
- Bidding strategies, bid preparation and award implementation.
- Capabilities for sensor data handling (time, temperature,...), monitoring and archiving, and communication.

For the node representing the utility:

- Knowledge about utility demand-side management goals and requirements.
- Knowledge about pricing policies and financial incentives for load management.
- Cost-benefit calculations regarding peak/valley load reductions and total energy demand.
- Negotiation procedures, covering bid term setting (announcements), assessment of received bids vis-à-vis utility goals, and awarding policies under varying circumstances.

- Monitoring, archiving and communication facilities.

Added Value It is rather straightforward to develop measures for the added value delivered by load management, both for the utility and the customer. For the customer, it is reduction of energy consumption and of energy costs; for the utility it is peak load reduction and overall energy savings. These can be easily quantitatively expressed and compared to the reference situation where there is no load management at all. Another interesting reference situation is provided by energy system simulations (for which there exist large linear-programming models) that are able to calculate the maximum possible optimization in an energy system resulting from various measures. These models, by the way, also yield economic knowledge needed for the cost calculations by the HOMEBOTS. So, we have two extreme reference situations that can be employed to position the HOMEBOT load management results. Studies by Linköping University for various towns and industries indicate that load management may save about 5% of the power peak demand consumption. This strongly depends on the characteristics of the local situation and on other energy-saving measures that can be implemented. For the Municipality of Ronneby, where the field tests for the ISES and HOMEBOT projects are planned to be carried out, a recent energy system simulation study indicates that load management is indeed attractive both for the power supplier and the customer [9].

Resources The HOMEBOT load balancing process consumes significant resources. A first, operational one is time: negotiations must be concluded within the allocated time. Given the limitations of the available infrastructure, there is a common interest to keep negotiations, communication and calculations rather fast and simple. Computing and communication limitations are more severe at the customer side (where we only can expect very small distributed microprocessors) than at the distributor side (where the substation nodes can be given the capabilities of a decent PC).

A second one is financial costs. Both the additional investment and operational costs for installing and operating the needed infrastructure have to be calculated and taken into account in the above-mentioned added value considerations. However, much of the needed information and communication infrastructure can be shared with other new services.

A third one in the further future might be so-called opportunity costs. If the same infrastructure is heavily used for many different services, they may compete for resources. Given a choice, it might be that you could have used your money in another and better way.

Performance Performance measures for the HOMEBOTS process can be derived from elements already discussed previously. Time: is the process concluded within the available time? First-pass yield: does the first round of negotiations already yield suitable results, or are many iterations needed? Stability: does the process converge well, or are there instabilities that must be countered? Resources: does the process stay within the communication and computation limitations of the available infrastructure? Savings: does the process indeed yield energy and / or financial savings, and if so, to what extent?

At the current stage of the HOMEBOTS project, the focus is on meeting operational and resource constraints: simple and efficient negotiation, limited communication, fast convergence. These requirements can be successfully met, as discussed in the next section.

4 Implementation and First Results

The HOMEBOTS load management service has currently been implemented in a simulation environment, with which test runs of the new business process are performed, before field tests (envisaged for 1997 / 8) will be carried out.

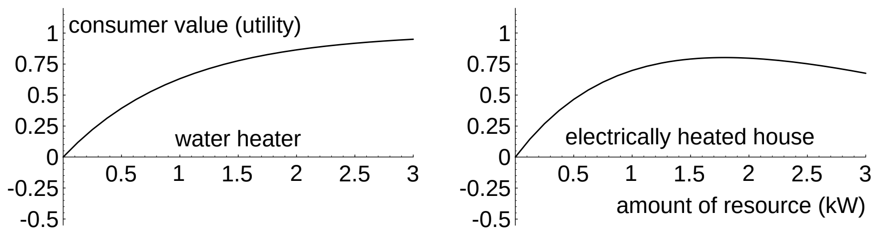

Figure 5: Typical utility functions.

Technically, it is a multi-agent system [10– 13], whereby needs and preferences of the agents are modelled by a *utility function* describing how valuable it is to an agent to have a certain share of the resource (here, electrical power). Typical utility curves are given in Figure 5. The system then behaves as a computational market economy [11,13], with the overall goal to maximize the total utility of the society through a process of bidding by each agent in an auction. After each bidding round, the designated auctioneer agent computes an updated optimum power allocation, until a global optimum is achieved.

It is noted that the utility cannot exert global control: it acts as just one agent among many. So, it can only influence the situation in a decentralized fashion. One simple control strategy is depicted in Figure 6: if the utility wants to carry out a load management action, it can reduce a peak load by bidding a higher price. What effectively happens is that the utility then ‘buys back’ energy from those customer load agents that attach a smaller value to their current share of the resource. This is what we see in the figure: at time 7 the utility agent (upper curve) changes its bid price; then, the other agents reduce their energy consumption and sell part of their power to the utility, until a new equilibrium is reached at time 9. The time unit used here is one bidding round, so convergence of the process is very fast — as it needs to be in a real-time setting.

Details of our computational market design are given in Refs. [12] and [13]. Here, it suffices to point out that we exploit quantitative economic ideas (especially the micro-

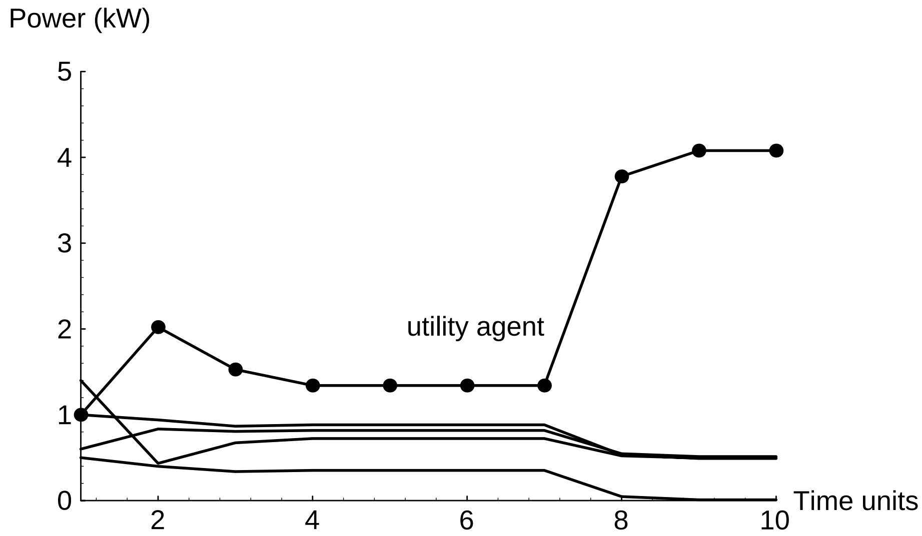

Figure 6: Dynamic simulation of a load management scenario, resulting from changing the bid price by the agent representing the energy utility.

economic [14] notion of utility), combined with concepts and algorithms from mathematical optimization. This has several advantages. First, customer knowledge and preferences are very concisely summarized in terms of a relatively simple consumer value or utility function. Secondly, the resulting distributed optimization problem (which is rather complex) is open to mathematical analysis. This is important to ensure certain required properties of the process (for example, under appropriate and rather realistic conditions we can guarantee that the process will lead to a unique optimum). Thirdly, we can exploit known quantitative properties of computational methods, to improve the operational resource and performance aspects (for example, efficiency in communication and convergence speed).

Finally, it is noteworthy that our computational market design has excellent scaling properties. Simulation runs with up to 1000 agents have been carried out and show a dynamic behaviour similar to that in Figure 6. Thus, the present approach leads to a very effective as well as efficient solution for decentralized energy management services.

5 Knowledge Management Implications

Above, we have discussed in some depth a case of innovative service development, viz. that of decentralized load management in energy utilities. It shows most of the characteristics proposed by Davis and Botkin [15] of what they call knowledge-based or 'smart' products and services, which in their opinion will dominate the next wave of economic growth. Beyond its proclaiming, however, the knowledge-based economy calls for new concepts, methods, tools, and experiments, and this is why the field of knowledge management is of extreme importance.

We believe that knowledge management, at its present stage of scientific development and managerial acceptance, is in need of extensive case material: this constitutes the empirical 'data points' needed to build and validate a coherent knowledge management theory. In this section, we will consider the general implications for knowledge management following from our case, and relate them to ongoing work.

5.1 Knowledge orientation in business task analysis

Business, organization and technology issues have to be analyzed and solved together in a single framework. Current methodology still shows the signs of its originating from separate disciplines (BA, IT). Multi-disciplinary work is a sine qua non in knowledge management, and extension and integration of existing methodologies is necessary to overcome present limitations. The now popular object-oriented methods (e.g. [4,7]) are a case in point. Although a significant step forward, they do not suffice, neither as a framework for knowledge management (or BPR [4], for that matter), nor to fully realize the potential of IT in the knowledge-based economy (cf. [16]). *Knowledge orientation* gives a better coordinating perspective. Here, we share many of the views proposed by, for example, Van der Spek and De Hoog [17]. In the previous sections, we have analyzed several elements of what knowledge orientation should be in both the organizational and technological sense, and how it works out in a practical case.

5.2 From knowledge value chain to value system

In analogy with Porter's value chain, it is natural to come up with a knowledge value chain (e.g. [1,18]). For example, Weggeman [18] discusses knowledge management activities, ranging from identifying available and needed knowledge, strategic knowledge planning, developing / acquiring / fostering / distributing knowledge in the organization, to disposal of knowledge that has become irrelevant. These activities form the elements of a knowledge value chain which on its turn is embedded in a cyclic model of organizational learning [19], with the Mission-Goals-Strategy set of the organization as a driving force. In different terminology, Van der Spek and De Hoog [17] describe similar knowledge-management activities. They also propose a cyclic model of knowledge management, consisting of conceptualize-reflect-act-and-review actions. This is, like [18], based on Argyris' model of double-loop learning [19], and it is also very reminiscent of Boehm's spiral model that in adapted form is widely applied in knowledge-based project management [8].

Not only knowledge within the organization, but also customer knowledge may be mobilized for new products and services. Thus, the customer becomes *co-producer of value*, which contradicts the conventional idea of a linear value chain. This is an important point generally made by Wikström and Normann [1] and practically demonstrated by our HOMEBOTS case. This has direct implications for knowledge management as well. The knowledge value chain must be expanded to a wider *knowledge value system*, which not only includes the organization itself, but also the knowledge of suppliers and customers. In very practical terms, in the HOMEBOTS project we will, jointly with other subprojects within the ISES effort, in the near future study the information-use and decision-making styles of customers vis-à-vis load management. Quite some effort will go into finding out *how* customer knowledge must be represented and packaged for a specific purpose. In general, knowledge management requires a systemic framework regarding value creation.

5.3 Shaping the 'web' organization for knowledge creation

The knowledge creation necessary for new intelligent products and services necessitates the shaping of new organizational forms. Various factors contribute to this.

Exploiting the emerging IT capabilities interacts with what is considered as *valuable knowledge*. In our case, certain corporate as well as customer knowledge (e.g. on energy consumption patterns) already exists for a long time, but has traditionally not been viewed as an asset that is exploitable. Knowledge capitalization thus is not a static concept, but has to be reviewed periodically in the light of new technological opportunities. Relevant new knowledge can come from new and unexpected sources.

Furthermore, the levels of available knowledge differ widely. Bohn [20] has defined a scale for this, ranging from simple awareness that a factor plays a role to hard scientific theory. In combining knowledge for new knowledge-based services, we have to deal with very different levels at the same time. Bohn seems to suggest that for an application one should strive for the same high overall level of knowledge, but we think this is neither necessary nor practical. Nevertheless, assessing the existing levels of technological knowledge in respective areas is important in strategic knowledge planning.

Although much relevant knowledge is available, it usually exists in strongly distributed forms. In the ISES effort, for example, we have to deal with geographical spread (four different European countries being involved at the moment), a variety of contributing industry branches, and a wide range of relevant scientific and technological disciplines. The many different knowledge carriers that are part of the overall knowledge value-creating system must be brought together.

More and more, the *inherent distributedness of knowledge* will simply become a fact of life. This makes it necessary to explore new shapes of the organization for knowledge creation as well as knowledge combination and packaging into new products and services. In this context, Nonaka and Takeuchi [2] speak of the 'hypertext' organization. Within the ISES project, forms of the 'virtual organization' are explored [21]. Although much experimentation is still needed, it is clear that needed organizational shapes have strong *web-like* properties. Most fundamental, however, is the point put forward by Guyot [22]. Realizing and bundling the *return of experience* is the key consideration in the question how to shape the organization for knowledge management.

5.4 The importance of visioning: guiding metaphors

A reasonable and practical definition of knowledge management is: a framework and tool set for getting the right knowledge to the right people in the right form at the right time. Many such frameworks for knowledge management [17,18,20,23] seem to be mainly geared towards improving current business activities. In our case, we are dealing with knowledge creation for not yet existing business activities, and we believe that the situation is a bit different here. In line with Nonaka [2], we emphasize the crucial role of visioning in the knowledge creation process. In particular, the ongoing process of generation, refinement, and elaboration of metaphors is a highly important, and currently undervalued, aspect of knowledge management.

This is clearly visible in the ISES project. Its overall aim is summarized in Figure 1, and can be expressed in terms of new services through 'two-way communication' with the customer. This is basically a metaphor. It is used to give all participants a global sense of direction, and the output of the project essentially is to establish what such a metaphor means in practice, both in technological and in business terms. Within the various subprojects, we find what we may view as submetaphors: the 'ideal dialogue' (with the customer), information 'kiosks', the 'virtual vs. physical' organization, the 'interactive bill'. The notion of a HOMEBOT itself is a metaphor (deriving from Asimow's robot stories and the Star Trek episode mentioned before). Its realization is also guided by a concept that provides a clear refinement, but still with a high metaphoric content: that of the computational 'market'. Here, we also see at work the process of how to elaborate metaphors and making them more concrete. The microeconomic theory of competitive markets [14] is being turned from an interesting but rather abstract academic playfield, into a viable IT approach with real industrial application in offering innovative services.

Nonaka states that the generation of guiding metaphors is the top-down part of his middle-up-down management. This, we believe, is an oversimplification. Useful vision elements and metaphors come from different knowledge carriers that are part of the value system. In a heterogeneous and distributed knowledge value system, they constitute a practical instrument for the needed return of experience. Their function is not only to enable the combination of different pieces of knowledge but also to help achieve what Tsuchiya calls *commensurability* [24]. This notion, put forward already some decades ago in work in the philosophy of science by e.g. Kuhn and Feyerabend, acknowledges that different participants enter with different images, interests and paradigms concerning the same situation. Knowledge sharing is not really possible without making these images more compatible, and collectively elaborated guiding metaphors are instrumental in this. Web-like forms are useful in shaping this process organizationally.

Concluding, we may concisely summarize this by the 'equation':

$$\text{knowledge creation} = \text{visioning} + \text{return of experience} \tag{1}$$

Acknowledgements. We thank Hans Ottosson (CEO of EnerSearch AB, Malmö, and director of the ISES project) for encouragement and support.

References

[1] S. Wikström and R. Normann : *Knowledge and Value — A New Perspective on Corporate Transformation*, Routledge, London, 1994.

[2] I. Nonaka and H. Takeuchi: *The Knowledge-Creating Company — How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press, Oxford, 1995. A summary of the key points is found in the Harvard Business Review, November-December 1991, pages 96– 104.

[3] C.D. Winslow and W.L. Bramer: *FutureWork — Putting Knowledge to Work in the Knowledge Economy*, The Free Press / Macmillan, New York, 1994.

[4] I. Jacobson et al.: *The Object Advantage — BPR with Object Technology*, Addison-Wesley, Reading, MA, 1994.

[5] James Martin: *Information Engineering*, (three vols.). Prentice-Hall, Englewood Cliffs, NJ, 1990.

[6] E. Yourdon: *Modern Structured Analysis*, Prentice-Hall, Englewood Cliffs, NJ, 1989.

[7] J. Rumbaugh et al.: *Object-Oriented Modeling and Design*, Prentice-Hall, Englewood Cliffs, NJ, 1991.

[8] A.Th. Schreiber, B.J. Wielinga, J.M. Akkermans, W. Van de Velde, and R. de Hoog: *CommonKADS — A Comprehensive Methodology for KBS Development*, IEEE Expert Vol. 9, Nr. 6 (December 1994) pages 28– 37.

[9] Ulrika Bergström, Sydkraft Konsult AB, Malmö, Sweden, private communication, September 1996.

[10] Staffan Hägg and Fredrik Ygge: *Agent-Oriented Programming in Power Distribution Automation*, Lic. Thesis Lund / Ronneby, 1995.

[11] M.P. Wellman: *A Market-Oriented Programming Environment and its Application to Distributed Multicommodity Flow Problems*, Journal of Artificial Intelligence Research Vol. 1 (1993), pages 1– 23.

[12] F. Ygge, R. Gustavsson and J.M. Akkermans: HOMEBOTS: *Intelligent Agents for Decentralized Load Management*, in Proceedings of the Conference on Distribution Automation and Demand-Side Management DA / DSM'96 Europe, Vienna, Austria, October 8– 10, 1996. In Press.

[13] F. Ygge and J.M. Akkermans: *Power Load Management as a Computational Market*, in Proceedings of the 2nd International Conference on Multi-Agent Systems ICMAS'96, Kyoto, Japan, December 1996. In Press.

[14] H.R. Varian: *Microeconomic Analysis*, W.W. Norton & Company, New York, Third Edition, 1992.

[15] S. Davis and J. Botkin: *The Coming of Knowledge-Based Business*, Harvard Business Re-

view, September-October 1994, pages 165–170.

[16] A.Th Schreiber, J.M. Akkermans, and B.J. Wielinga: *Integrating Knowledge and Software Engineering*, Universities of Amsterdam and Twente, The Netherlands, 1996.

[17] R. van der Spek and R. de Hoog: *Towards a Methodology for Knowledge Management*, in J-P. A. Barthès (Ed.), Proceedings 2nd International Symposium on the Management of Industrial and Corporate Knowledge ISMICK'94, pages 93–102, IIIA, Compiègne, France, 1994.

[18] M. Weggeman and T. Boekhoff: *Knowledge Workers and Knowledge Management*, Holland Management Review, No. 42, pages 80–89, 1995. In Dutch. See also the contribution to ISMICK'96.

[19] C. Argyris: *On Organizational Learning*, Blackwell Publishers, Cambridge, MA, 1992.

[20] R.E. Bohn: *Measuring and Managing Technological Knowledge*, Sloan Management Review, Fall 1994, pages 61–73.

[21] P.M. Bosch-Sijtsema and J. Bosch: *Virtual versus Physical: The Future?*, ISES project report, Enersearch AB, Malmö, and HK/R, Ronneby, Sweden, August 1996.

[22] J. Guyot: *Improvement of Knowledge Capitalization in the Enterprise: Elements of the PSA Peugeot-Citroën Approach*, in J-P. A. Barthès (Ed.), Proceedings 2nd International Symposium on the Management of Industrial and Corporate Knowledge ISMICK'94, pages 35–43, IIIA, Compiègne, France, 1994.

[23] K.M. Wiig: *Knowledge Management Methods — Practical Approaches to Managing Knowledge*, Schema Press, Arlington, Texas, 1995.

[24] S. Tsuchiya: *Commensurability — A Key Concept of Business Re-Engineering*, in J-P. A. Barthès (Ed.), Proceedings 3rd International Symposium on the Management of Industrial and Corporate Knowledge ISMICK'95, pages 81–87, IIIA, Compiègne, France, 1995.