Agent-Based Digital Networking in Furniture Manufacturing Enterprises

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Abstract. International competition and varying customer needs commonly cause small and medium furniture manufacturing enterprises to join dynamically-formed, 'smart' enterprise networks, established and operating using digital information technologies. In this paper, we propose a technological approach to support such enterprise networks which is primarily based on the use of software agents. First we outline the reasons motivating networking in furniture manufacturing enterprises and we briefly present core smart enterprise network concepts. Subsequently, we provide an overview of the main technologies currently used to support enterprise networks, and we make the case for utilising service-orientation and adaptive, (semi-) autonomous software components, such as software agents. Furthermore, we propose a four-tier software architectural framework based on software agents and web services, and we briefly describe the requirements, the architecture and main features of the e-Furn software system, which is based on that framework. Finally, we discuss the intelligent recommendation feature of e-Furn.

Keywords: Smart Business Networks, Enterprise Networks, Software Agents, Multi-Agent Systems, Web Services, Furniture Manufacturing, Data Mining.

1 Introduction

To cope with increased competition and dynamically varying customer needs Small and Medium Enterprises (SMEs) join dynamically formed collaborative networks. In such networks, participants can exploit the competencies offered by network partners to improve their efficiency and meet the stiff market demands. Such business networks have a number of characteristic features, the prominent one being their dynamic nature and flexibility in participation. For these reasons they are termed 'smart'. In Smart Business Networks (SBNs) members act solely towards achieving their personal goals and maximizing their individual benefits. This contrasts other forms of enterprise networks and virtual organisations, where there is a different sense of membership and members aim to increase their individual benefit by acting towards the benefit of the whole organization.

The dynamic nature of smart business networks makes the use of software agents mandatory in developing software to support their operation. Agents offer flexibility

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and interoperability while they can provide both decentralised and inherently adaptive coordination and control. Furthermore, to better support the regularly changing business network competencies it is necessary to combine agent capabilities with service-orientation in the design of the software architecture.

In this paper, we present an agent-based approach to support 'smart' networking in furniture manufacturing SMEs. The motivation for 'smart' networking in furniture enterprises and a brief description of main SBN concepts are presented in Section 2. Section 3 provides an overview of digital technologies currently used to support enterprise networks and makes the case for using service-orientation and adaptive components, such as web services and software agents. Based on these arguments a four-tier software architectural framework is proposed in Section 4, and as an example of application of this framework an overview of the e-Furn system is given in Section 5. Finally, Section 6 concludes the paper.

2 Motivation and Background

2.1 Networking in Furniture Manufacturing SMEs

The global financial crisis which has recently hit EU has forced many furniture manufacturing SMEs to reduce their product range and their production capacity attempting to reduce costs. In addition, increased competition and sophisticated customer demands has often led furniture manufacturers to specialisation in a small range of products aiming to maximise product quality. However, such an approach has certain drawbacks. Customers often prefer to purchase complete solutions and the lack of variety shown by specialising manufacturers propels them towards larger stores with higher product ranges. In other cases, knowledgeable customers have done extensive market search, using the internet for instance, and have sophisticated product requirements that small furniture manufacturers can not individually meet.

To address such problems furniture manufacturing SMEs have traditionally tended to form relatively stable partnerships and alliances, for example small manufacturers commonly market both own and partner products showing this way a higher product range to customers [1, 2]. Such approaches have been sufficient until recently when customer demands were relatively stable and product ranges were more or less fixed or rarely changing. Today, however, this is not the case due to the aforementioned reasons. As a result, to tackle the above issues furniture manufacturing SMEs need to be able to form dynamic and flexible partnerships involving more partners and providing access to a wider range of customisable products. In this respect, the existing forms of business networks, such as clusters and static virtual enterprises are not sufficient.

Another issue of major concern in furniture manufacturing SMEs is the efficient use of resources. To achieve high product quality and to cover a large number of customisation options, expensive equipment with high maintenance costs is needed, which is not fully used due to low production levels. Traditionally, an approach to mitigate this problem has been to carry out outsourced manufacturing tasks from selected partners at an agreed cost. Again, due to the relatively stable types of products, outsourced tasks were more or less known and suitable outsourcing partnerships were selected shortly after a new product was decided and were maintained during the most part of the product lifecycle.

Today, however, this is also not possible. The increased product customisability makes outsourcing manufacturing tasks even harder. For example, a furniture manufacturing SME in South Europe specialising in wooden furniture will typically have equipment and outsourcing partnerships suitable for European markets. A customer, such as a hotel, may require sophisticated, e.g. baboo-type, furniture needing specialised processing not capable of being carried out in-house. In that case, the manufacturer would need to immediately know the best outsourcing options, even internationally, in order to produce the most competitive quote to the customer in the shortest possible time. This would not be possible with traditional methods.

From the above arguments, it is evident that traditional forms of enterprise networking are not sufficient to meet current challenges faced by furniture manufacturing SMEs. We argue that the solution to this problem is to provide the technological means for such enterprises to rapidly join dynamically formed business networks and within them to form 'smart' collaborations acting rationally to promote their goals while benefiting from the overall network context and collaboration infrastructure.

2.2 Smart Business Networks

An SBN is a collection of dynamically connected enterprises linked to each other and acting smarter than any individual business can [3]. SBNs are characterised as 'smart' because of the add-on value they provide to their members in terms of goods, products, services and experiences, as well as in terms of the possibilities individual members have to organise themselves and collaborate in innovative ways. The most important key characteristic of SBNs is their ability to demonstrate agile behaviour, for example by allowing their members to rapidly "pick, plug, and play" [4] business processes and reconfigure them to meet specific objectives, such as react to customer orders and cope with unexpected situations. The term *"pick"*, refers to the possibility for members to quickly connect to and disconnect from the network, while the term *"plug"* refers to the ability of members to select and globally execute business processes across the entire network. Finally, the term *"play"* refers to the ability of members to establish their own decision rules and business logic in the above mentioned business processes. A typical example of 'smart' add-on value gained in an SBN is the dynamic exploitation of market opportunities, such as identifying and filling unfilled market positions (termed 'structural hole strategy' in [5]). This outstanding agility of SBNs has only been enabled through the latest developments in information and communication technologies [6]. In particular, SBN 'smartness' does not only result from the dynamically formed and adaptively modifiable business models applied, but also from the sophisticated combinations of the state-of-the-art ICT technologies used [7].

A schematic representation of two SBNs is depicted in Figure 1. Each SBN has a node acting as coordinator which all other SBN members are connected on. An SME joins an SBN by registering with the respective coordinator node and subsequently it can access all other SBN members and establish contacts and collaborations as needed.

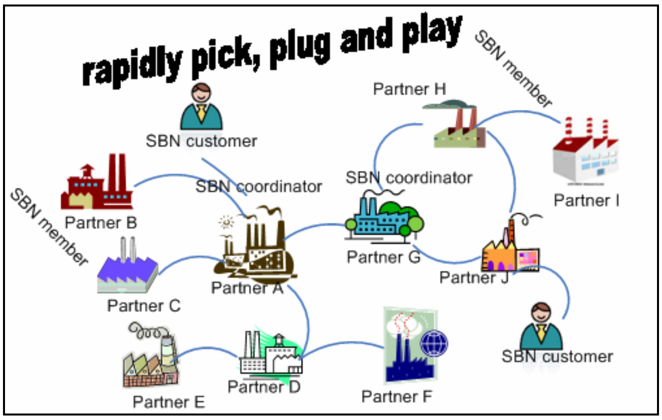

Fig. 1. A Smart Business Network

3 Supporting SBNs with Digital Information Technologies

3.1 Overview of SBN Support Technologies

As mentioned in Section 2.2 'smartness' in SBNs is largely a matter of utilising and appropriately combining advanced ICT methods. To this purpose, various technologies have been so far used to support operations of such networks. Examples are Semantic Web Models, Tools and Ontologies, Web Services (WS), Grid Computing, Sensors and Radio Frequency Identification Devices (RFIDs), and Software Agents. A survey of such technologies is summarised in Table 1.

An example of using semantic web technologies for enabling business network operations is the work described in [8], which focuses on mechanisms for enabling rapid connectivity between network partners. The approach involves the use of OWL ontologies to build interfaces between partner systems, which expose their public functionality in the form of services. In that model, the logic connection between services is realised by associating services with pre-conditions and post-conditions which describe in detail, and according to the agreement of the business partners, the conditions that must be satisfied for particular services to be invoked to ensure interoperability between partner systems. However, that approach focuses only on predefined services and does not support dynamic service composition and configuration of partner collaborations, for example by means of negotiation.

Once partners in a business network have "picked" and "plugged" the appropriate process modules together, these need to be executed. This has often been supported by using Web Services. For example in [10] an approach involving using Web Services and handling dynamic adaptations of business network behaviour with suitable WS orchestration is described. However, the disadvantage of using only WS is that high orchestration and coordination costs are involved (for example when searching for appropriate services, negotiating for price and quality of services and monitoring B2B transactions) and therefore we argue that a form of technological intelligence should be added to WS to better support operations of business networks.

Table 1. Technologies used to support Smart Business Networks

Technology	Approach	References
Semantic Web Models, Tools & Ontologies	Used for automatic and fast interoperability between many different systems.	Xiao and Zheng [8] Werthner, Fodor and Herzog [9]
Web Services	Used to integrate the computer applications of different participating firms and facilitates the connect and disconnect method, and can be used together with the other technologies.	Hillegersberg, Boeke, and Heuvel [10] Busquets, Rodona and Warehama [11]
Radio Frequency Identification Devices (RFIDs)	Used for reducing costs, improving service levels and offering new possibilities for identifying unique product instances.	Rodon, Busquets, and Christiaanse [12] Pramatari and Doukidis [13] Pramatari, Doukidis and Kourouthanassis [14]
Grid Computing	Used for improving organisational agility to respond to rapidly changing requirements, for example to cope with disasters.	Oosterhout, Koenen and Heck [15] Boden [16] Chen et. al [17]
Software Agents	Used for supporting organisational decision-makers in making multi-attribute decisions in environments that are characterised by a high velocity of change.	Collins, Ketter and Gini [18] Douma et. al [19] Ketter et. Al [20]

In [12] an approach for tracing a company's products based on the use of RFID technology is described. The approach involves a specialised business operating system which is responsible for coordinating the process among nodes on a business network. Products are tagged with RFIDs and there is both a global business knowledge store, as well as a number of industry wide local repositories which are shared via intranet and extranet connections. However, that approach lacks flexibility, for example it considers statically predefined products.

Oosterhout et al in [15] use grid technology and demonstrate how it can improve organisational agility to be able to respond to rapidly changing circumstances. In that paper, the authors describe a business experiment involving development of an application solution for backup and recovery of enterprise data. That solution is based on sharing data storage hardware by users in a grid. This approach however, does not provide full-scale support for SBN operations.

Collins et al in [18] show how intelligent agents can support organisational decision-makers in making multi-attribute decisions in highly dynamic environments. They present an architecture that offers innovative capabilities for automatically connecting, disconnecting and communicating with the appropriate actors in a business network. They offer a technological solution for companies to create the highly needed quick-connect capabilities allowing companies to change its position in the network more swiftly. However, that approach does not use standardised technologies, such as WS.

In summary, semantic web approaches solve the interoperability problem, but they currently suffer from lack of universally applicable standardised technologies, as well as from effective support for implementing flexible and adaptive behaviour. Standardisation and industrial strength technologies are ensured by using Web Services, RFIDs and Grid technologies. However, these technologies suffer from interoperability and flexibility problems. Finally, adaptivity and flexibility is addressed by using software agents. However, agents too currently suffer from lack of broadly accepted, industrial strength technologies, for advertising and executing their services. Therefore, we argue that a combination of agent and WS technologies would be required to support 'smart' business networking operations.

3.2 Service-Orientation and Flexible, Adaptive Software Components

As described in the previous Section there are different technological approaches that can be followed to develop support for SBN operations. We advocate the use of the *Service-Oriented Architecture (SOA)* approach. SOA can be seen as an application architecture in which all functions are seen as *services* [21]. Services are capable of being remotely invoked by external users and by other services and they encapsulate application logic with a uniformly defined interface and are commonly made publicly available via discovery mechanisms [22].

The SOA paradigm has many advantages, for example it enables on demand linkage of users and computational resources. SOA is essential for delivering business agility and IT flexibility. A well-executed SOA implementation can bridge the gap between enterprise architecture and business strategy, enabling companies to achieve closer alignment of IT and business, and robust reuse of existing applications with agility and cost effectiveness [23].

However, SOAs do not provide any support for rational (semi-)automated selections when it comes to the creation of virtual organizations and enterprise networks. Such rational selection is crucial for establishing and operating viable business formations. This issue can be addressed by enriching SOA with software components with reasoning abilities or "intelligence". Software agents are particularly suitable for this task since they provide inherently adaptivity and flexible behaviour, both individual and collective in the form of Multi-Agent Systems (MAS). The benefits of combining SOA and agents are therefore increased flexibility and adaptability of enterprise network processes to suit varying individual organisational needs. However, still much research on the business and technical aspects of the combination of SOA and such components to support SBN operations is needed.

3.3 Software Agents and Web Services

SOAs are commonly, but not necessarily, implemented as web services leading to the issue of combining agents and web services [24]. Therefore, a main effort in the integration of agents and web services concentrates on masking services for redirection, aggregation, integration and administration purposes [25]. Although the evolution of MAS and web services has been completely different, both technologies have pursued common goals such as providing dynamic, open and oriented architectures. In order to solve their differences and to give interoperation and integration possibilities, various approaches have evolved, such as WSIG [25], WD2JADE [26] and ESWA [27]. These efforts, as pointed out in [28], can be classified in three categories. Firstly, WS can provide the most basic level functionality while agents can supply higher-level functions by using, combining and choreographing WS, so achieving added-value functions [26]. Alternatively, communication in WS and agents may become equivalent, so that there is no distinction between them ('agents in web service wrappers') [27]. Finally, both concepts can remain separate creating a heterogeneous service space and interoperating through gateways and translation processes [25].

Most of the current agent works strongly related with Web services do not take into account regulation aspects and they are mainly focused on heterogeneity problems in MAS systems. With this aim, they lean on an explicit description of the offered services, an approach which lacks expressivity and cannot serve as a basis for intelligent service orchestration and coordination. Therefore, it is necessary to employ expressive semantic languages, such as OWL for agent domain ontologies, and, as was originally suggested by Hendler [29], OWL-S for WS semantic annotation. In this way, new complex services will be able to be formed semi-automatically by agents and users.

4 A Four-Tier Software Architectural Framework

A commonly accepted view in software architecture research is that according to the principle of separation of concerns, software agents and web services must lie on different layers of abstraction due to the conceptual differences between them [30]. From a system designer's point of view, web services can be used to model passive software components that exhibit reactive, deterministic behaviour. On the other hand, proactive and autonomous behaviours are more suitably modelled by software agents. Agents have inherent flexibility and can represent stochastic, intelligent behaviours at various levels of autonomy. Application functionality, such as workflow process tasks, can be materialised both by agents and web services depending on the particular context. Finally, lower level software components encapsulating internal business logic, such as legacy systems and databases, can be accessed both by web services and agents according to the application requirements.

Therefore, we propose that software architectures aiming to support smart business networks should be lying on four layers (see Fig. 2). The lower layer, namely, the Business Logic Layer provides for the most specific operations. It comprises the internal business processes within companies. It usually consists of conventional ERP system components. Upon this layer, Web Services are deployed exposing parts of the internal business processes and making them publicly available. These services along with the semantic description of their capabilities lie on the second layer, namely the Web Services Layer. Adding semantic annotations to web service capabilities can help software entities, such as software agents, to (semi-)automatically interact with them in a dynamic way.

Agents interact with, and take advantage of basic services and they are located at the Agent Layer. Agents make use of the semantic annotation of services capabilities

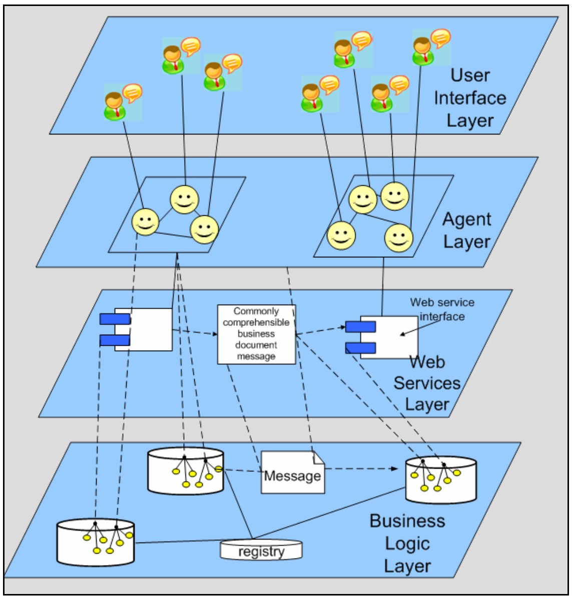

Fig. 2. Four-tier Architectural Framework based on Agents and Web Services

to automatically discover, compose, invoke and monitor web services. They are also able to dynamically exhibit and propagate the changing functionality provided in lower layers. Finally, the User interface Layer is responsible for interacting with users and organising (for example configuring and guiding) agents to execute networked business processes. In this way, depending on the agents available in the system and the way they interoperate, different user-tailored ‘smart’ networked applications can be produced.

5 The E-Furn System

As an example of a system following the software framework introduced in Section 4 we present a high-level view of the e-Furn system. e-Furn aims at supporting smart networking of furniture manufacturing enterprises [31]. The approach followed in the development of e-Furn is to use as standardised mature technologies where possible, and combine and extend these technologies to address the furniture enterprise SBN domain requirements. To this purpose, an approach combining agent-technology and service-orientation has been selected.

The e-Furn system (see Figure 3) has been designed following the principle of separation of concerns, considering four layers: the Business logic layer comprising legacy systems and other information resources, the WS and the agent layers corresponding to WS and agents respectively, and the user interface layer where the capabilities of all other three layers are combined to produce ‘smart’ business networking functionality. The system is viewed a grid of distributed interconnecting partner nodes that are all linked with each other. One of the nodes is considered the main e-Furn

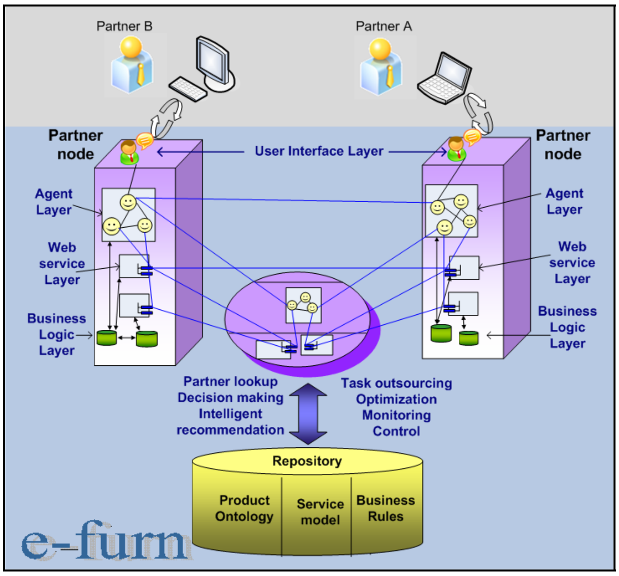

Fig. 3. Overview of e-Furn System Architecture

node and acts as coordinator of the other nodes, for example for intermediating to establish communication for new partner nodes joining the network, and for resolving conflicts that may arise. To establish communication, new partner nodes get in contact with the main e-Furn node and after necessary authorisations they obtain access to the partner details, such as addresses and available services. The e-Furn is considered to be an open system based on software agents in the sense described in [32, 33].

5.1 SBN Support System Requirements

Based on the needs for 'smart' networking furniture industry SMEs we identify a number of high-level requirements for the e-Furn system:

RQ1: The system should be able to support new enterprise member registration and authorisation procedures which should be able to be carried out dynamically and on run-time. e-Furn end-users will be employees of registered e-Furn member enterprises, such as salesmen for instance, and not end customers.

RQ2: For each e-Furn member enterprise, employees with necessary privileges should be able to locate and select other appropriate e-Furn member enterprises and designate them as collaborators by placing them in groups created for this purpose.

RQ3: e-Furn member enterprises should be able to publish their products and services they wish to offer for reselling or outsourcing respectively. In particular, they should be able to specify general as well as specific parameters for product offer and service provision.

RQ4: e-Furn end-users should be able to receive technological assistance in their interactions with other users within the e-Furn network. In particular, repeated or standardised interactions should be able to be carried out (semi-)automatically requiring only final confirmation from the user. For example, the price of products offered by other network member enterprises should be possible to be finalised via semi-automated negotiation. Users should be assisted in carrying out such negotiations in short time and for a large number of products.

RQ5: Since the number of options and combinations will generally be large, end-users should be able to receive intelligent recommendation assistance for preparing the best offers for the customers and for selecting the best outsourcing options. The system should be able to estimate the combinations that are more likely to increase customer satisfaction and maximise the sellers profit and provide a list of options to the user who will finally select the best one based on her experience.

RQ6: e-Furn users are expected to have different needs and preferences which will normally be changing based on the form and type of collaboration. System interfaces should be able to adapt to user needs both statically based on user configuration, and dynamically based on collaboration and usage results. For example, if a user tends to prefer certain products of a certain type then these products should be able to be conveniently accessible by that particular user.

RQ7: Users should be able to monitor the status of their product orders, product delivery and execution of their outsourced tasks. It must be noted that furniture product particularities should be taken into account. For example, furniture products have specific packing and storing requirements, for instance they require much more storage volume than their actual mass.

RQ8: Users should be able to expose only part of their local information as and when needed. Any information exchanged should be revealed only to the intended recipient.

5.2 Main e-Furn Features

The main architectural elements of the e-Furn system are software agents that act as mediators between system components. Each external actor to the system, for example service providers, service users and system administrators, is associated with a software agent acting on her behalf, interconnecting the actor with the rest of the system and providing assistance. Agent behaviour is modelled using roles, as suggested in [34] and [35]. Agents make use of various (external or internal) data repositories, (stored in the form of ontologies) containing the knowledge that is to carry out the system operations and based on input from users they adaptively orchestrate system functionality which is provided in the form of web services. Adaptation and overall behaviour is further determined with global as well as individual for each partner business rules. All global network information is stored in the main e-Furn repository.

Among the main features of e-Furn are polymorphic user interfaces that adapt dynamically to user preferences and to system operation results. Furthermore, there are sophisticated decision making tools embedded in the system assisting users in operational decisions such as partner lookup. Another important feature of e-Furn is support for outsourcing tasks to partners and it provides advanced optimisation and task allocation tools that are manipulated by software agents and can be invoked by users to facilitate outsourcing of tasks with minimal costs. This is accompanied with

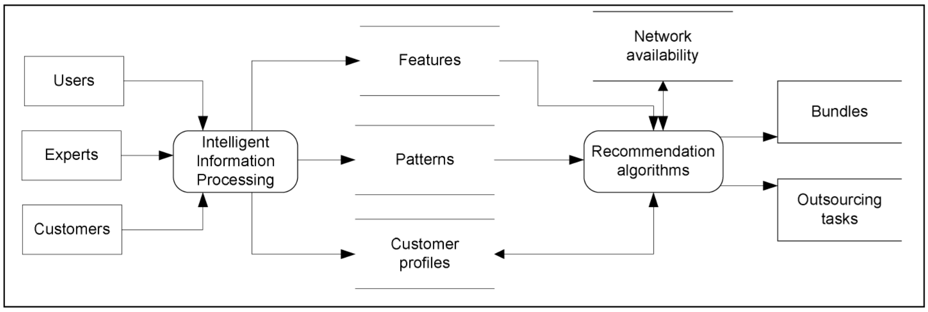

Fig. 4. Intelligent Recommendation Process in e-Furn

effective monitoring and control mechanisms allowing examination of the execution stage of outsourced tasks. Finally, e-Furn provides intelligent recommendation assistance through specialized recommendation algorithms, which is further described in Section 5.3.

5.3 Intelligent Recommendation Subsystem

E-Furn provides users with intelligent recommendation assistance, based on advanced *recommendation algorithms* that take into account furniture features, patterns and customer profiles to formulate and propose bundles of furniture and services. These are cross-referenced with a database of current network capabilities to produce a set of outsourcing tasks, as depicted in Figure 4 and detailed in the following paragraphs.

E-Furn comprises and maintains a database of features concerning furniture, not only in a standalone fashion (such as colour, price, dimension, weight, style, material, utility etc.), but also with regards to other furniture or domestic appliances in the broad sense. For instance, possible combinations can be considered (for example a set of chairs and a dinner table, kitchen furniture, and electrical appliances such as oven, fridge and dishwasher). These feature combinations can include matching schemes in terms of style, colour, utility and spatial collocation.

The system uses *innovative intelligent information processing methods*, including *association rule mining* from sales data stored in the customer database and furniture features to extract sales and configuration patterns [36-38]. For instance, the system can identify items that sell together, such as sofas and TV tables. It subsequently estimates the best selling price for this bundle, considering numerous additional parameters, such as customer details, customer sales history and profit expectations.

An important feature of our approach is the customer profile repository. This is initially populated using empirical data and information provided by experts, in terms of furniture arrangements suitable for a variety of business and domestic purposes, settings, budgets and so on. It is kept up-to-date and enriched using actual customer data, where customers can opt in a “loyalty scheme” in return for providing demographic and other information, such as individual preferences and requirements. All these data are mined in order to construct useful profiles. Initially we *cluster* customer related data in order to formulate clusters (i.e. groups) of customers [39]. These clusters indicate similarity across a number of dimensions including demographic, marketing, even subjective factors. These clusters can then be processed by intelligent agents in order to formally determine classes of customers which in turn can be used for customer classification [40, 41] and customer profile formation [42, 43].

Finally, e-Furn maintains a log of products and services, keeping tags on their availability within the network and elsewhere in real-time, using appropriate services/agents. Customer profiles, furniture features and patterns, along with availability information are fed into the recommendation engine, which is the core of the system. This engine matches potential customer requirements with provider's capabilities, in order to determine bundles of products and services. Priority is given to bundles involving existing network capabilities, but outsourcing is not excluded if necessary. In that case a list of outsourcing tasks is generated and relevant reservations are placed.

6 Concluding Remarks

As argued in Section 2, furniture manufacturing SMEs need to resort to enterprise networking to respond to contemporary global economic challenges. In this respect, traditional forms of business networking are not sufficient, given the current market state, the varying and sophisticated nature of customer requirements and the international competition. Therefore, we argued that furniture manufacturing SMEs need to join and operate flexible and adaptive, in other words 'smart', business networks, which in turn are highly relying on the efficient use of state-of-the-art ICT technologies to fully exploit their potential. Existing ICT methods currently used for supporting business network operations tend to be applied in isolation and therefore suffer from certain drawbacks, such as lack of adaptivity and flexibility. We argued on combined use of ICT methods and in particular on jointly using software agents and web services, and we described our perspective in the form of a four-tier architectural software framework.

As an example of a system based on the proposed framework, we provided a high-level view of e-Furn, a system aiming to assist furniture manufacturing SMEs in participating in 'smart' business networks. E-Furn is based on combined use of agents and semantic web services and its main futures include providing intelligent assistance and adaptive interfaces to users.

However, there are many issues relevant to providing robust and effective technological support for SBN operations in general, and furniture manufacturing SBNs in particular, that are still open. In the near future we plan to further elaborate on issues concerning provision of intelligence assistance to furniture manufacturing SBN members, such as product bundling recommendations and task outsourcing optimisation.

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