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# Federated Information Management for virtual enterprises

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# Chapter 6

# Conclusions and Future Work

## 6.1 Summary of General Approach

The VE paradigm represents an active area of research and technological developments, in which an extremely wide variety of existing ICT approaches, tools, components, models and standards can be applied. However, given the extension and complexity of the VE application domain, there are still many obstacles and open issues that need to be addressed, when supporting advanced collaboration scenarios among enterprises involved in VEs. Here, the proper sharing and exchange of information among pre-existing heterogeneous and autonomous enterprises and their internal systems, introduces particularly exigent challenges that are faced in the design of virtual enterprise support platforms. In this context, the general objective of this dissertation is the analysis, design and implementation of a federated Distributed Information Management System (DIMS), specifically tailored to properly support the complex requirements set forward by Virtual Enterprise collaborative scenarios.

The first step towards the accomplishment of this goal involved a detailed analysis of several related information management techniques and actual VE platforms, that need to be evaluated when designing and developing the information management system for a given virtual enterprise support infrastructure. The presented analysis included a survey of generic distributed information management techniques, related information representation models and standards, as well as several relevant information management technologies and tools. Furthermore, a representative set of international VE projects were selected, described and classified in terms of the main features applied for integration of the VE distributed information. These projects were also analyzed against a given set of criteria that was specifically defined in order to compare and evaluate their different features. In this way, the results of this analysis represent a survey of the *state-of-the-art* regarding the application of information management standards and technologies in existing VE support platforms.

Furthermore, in order to achieve a complete identification of the information management requirements for the target DIMS, a systematic analysis of the VE application domain was carried out. Namely, the analysis of the specific VE information man-

agement requirements for the DIMS was performed considering certain VE life-cycle scenarios supported by a reference VE Cooperation Layer, with emphasis on Industrial Manufacturing SMEs. The identified requirements included both the information modeling and the functional requirements for the DIMS. In addition, considering the results of the performed analysis, a clear need was identified regarding the application of the federated information management architecture, which in turn represents the generic framework proposed in this dissertation to support effective information sharing among the VE member enterprises.

Consequently, based on the identified distributed information management requirements and the proposed federated approach, the individual components of the federated database architecture were specifically designed and tailored to the VE application domain. Namely, the main components of the DIMS architecture were conceptualized, designed, and implemented, including: the federated VCL integrated schema, the DIMS Export Schema Manager Tool (ESMT), the Federated Query Processor (FQP), and the multi-user interoperable DIMS Server Agent. The export schema hierarchy definitions based on VE member roles and the workflow-driven federated query processing mechanisms, represent the features of the DIMS architecture that support the import/export of secure information among the federated nodes in virtual enterprises. Furthermore, the DIMS architectural components were applied to support real scenario cases within the industrial manufacturing domain considering the general PRODNET VE demonstration environment. For instance, some of the devised DIMS demonstration cases showed how the FQP mechanism works together with the ESMT access rights definitions in order to adequately support the management of distributed business process information, which becomes crucial for the proper coordination and monitoring of the tasks assigned to different VE members.

Finally, it was analyzed how the general DIMS federated approach can be tailored in order to cope with specific information management requirements encountered in different VE application domains, taking as an example the tourism sector. For this purpose, the presented DIMS requirement analysis, architecture design and system development phases were revised and adjusted to support Virtual Enterprises in the tourism application domain. In addition, it was demonstrated how several advanced Internet standards and development tools (e.g. Java, Jini, XML among others) can be incorporated in the architectural design and implementation platform of the federated information management system. Furthermore, it is expected that the federated information management architecture approach presented in this dissertation can also be applied to other kinds of VE application domains.

## 6.2 Summary of Achievements

The main contribution of this dissertation is the achievement of the design and implementation of a federated Distributed Information Management System that properly supports the cooperative information sharing and exchange, node autonomy, and information visibility levels and access rights for exchanged data among the VE nodes. Furthermore, other specific DIMS features or achievements regarding the management

of distributed information for the virtual enterprise domain are enumerated below:

- The DIMS integrated schema definitions are shared by all VE nodes and the data can be imported/exported from its source at the exact query-evaluation time, according to the proper access rights defined in the hierarchy of export schemas for VE partners. Consequently, distributed up-to-date data can always be accessed by the queries. Furthermore, this approach avoids the need for centralization of data and control over the VE nodes.

- The DIMS integrated schema represents and provides access to all the information classes that are necessary to support the operation of the VE Cooperation Layer as a whole unit. Different clusters of information required by individual components of this layer are linked together through a coherent and uniform database schema. In this way, the information for the VE Cooperation Layer components is well integrated to support the behavior of the global "VE entity".

- The general DIMS federated architecture represents a major distinguishing characteristic in relation to the approach followed in those other VE-related projects. In fact, similar architectures are only identified in other projects in which the CO-IM group of the University of Amsterdam has also been in charge of the VE information management system. For example, some of the federated database architecture functionalities enumerated in this section, provide particularly attractive features for handling several open-issues associated with the management of information in VEs, that have not been directly incorporated in other VE infrastructures and projects (see Chapter 2 for more details).

- The management of the hierarchy of VE partner roles and export schemas by DIMS, supports a flexible and configurable definition of information access rights among VE member enterprises, based on for instance: existing trust levels, production chain relations, legal contracts, and supervision clauses.

- The federated query processing of DIMS provides simultaneous access to the particular VE information for which an enterprise is authorized from several other enterprises, while hiding the physical data location details from the end users and client applications. For example, in the PRODNET scenario the generic DIMS federated query processor was applied in order to support order status monitoring among VE members from a given VE coordinator node.

- The DIMS server agent offers a wide variety of specialized high-level information management functionalities to support the VE creation and operation phases. These functions store and manage enterprise information according to a reference VE topology model, which is instantiated during the VE creation phase. For example, most of these functions expect both the VE identifier and the VE partner identifier as input parameters, in order to reinforce the consistent application of the VE paradigm concepts within different data sharing and exchange scenarios, specially when considering multiple VEs in the network.

- The DIMS federated database schema achieves a comprehensive integration of different information representation models and standards to support the VE operation. Namely, this integrated schema supports the representation of VE-related information in compliance with some of the ICT standards and models presented in Chapter 2, including STEP, EDI and DBP models.

- The DIMS architecture applies a combination of workflow management technology and federated/distributed database information management approaches, which has substantially contributed to support flexible and configurable interaction scenarios among both internal and external modules of the VE Cooperation Layer. For example, some specific interoperation scenarios were described in Chapter 4, addressing how the implementation of the DIMS federated architecture can benefit from workflow plan specifications; and conversely, how the workflow management engine can exploit the distributed information management services offered by the DIMS.

- The DIMS architecture also defines an interoperability mechanism to support data exchange functionalities between the VE Cooperation layer and internal enterprise systems. Through the proposed interoperability approach, the DIMS module can be dynamically integrated to interoperate with other internal company systems, such as ERP/PPCs.

- The modular development of DIMS within the PRODNET VCL environment provided the required level of security and message authentication for data exchange among enterprises, since it exploits different facilities offered by the specialized communication module of the VCL, e.g. PCI module in PRODNET.

- The DIMS implementation exhibits satisfactory levels of both reliability and efficiency, which are necessary to adequately support the regular operation of the VE Cooperation Layer. Namely, the application of careful design considerations during the entire DIMS software development life-cycle, the exploitation of a reliable internal DBMS, and the use of C++ as the development language for DIMS, have produced an information management system that satisfies the reliability and performance requirements of the PRODNET VE cooperation scenarios. A more quantitative performance evaluation of the DIMS could not be performed because the developed system is still a prototype (i.e. it is not a final engineering product that can be fairly tested using standard benchmarking methodologies). Furthermore, the performance evaluation of a complex systems such as DIMS, which is highly integrated with other VCL components, may also require to properly adapt traditional performance evaluation methodologies as most components are inter-related (it is not easy to make separate evaluations of each component per se), and this problem is outside the scope of this thesis.

- The DIMS federated architecture approach can be extended and adapted to support specific information management requirements derived from significantly different VE application domains, ranging from the industrial manufacturing to tourism sectors.

Considering the major achievements listed above, we conclude that the proposed design and implementation of the DIMS architecture can properly satisfy all the objectives and information management requirements for VE support, that were introduced in Chapter 1 of this thesis. Furthermore, the DIMS architecture represents a solid platform that can be extended in many directions, as described next.

## 6.3 Extensions and Future Work

This section describes a number of future research directions related to certain aspects of the work presented in this dissertation.

### 6.3.1 Management of Multiple VE Integrated Schemas

The presented DIMS federated approach has mostly focused on the support for VE collaboration scenarios in which there are a large number of international SMEs representing potential partners that can work together to satisfy a given business opportunity. The best way in which this kind of collaborations among international SMEs can be rapidly materialized and operate in an agile and reactive manner, is through the application of commonly defined information models and standards that minimize the associated semantic and structural heterogeneity that exists among the internal systems of these enterprises. This is the main reason for which it is assumed in the DIMS design that all the enterprises share the same integrated schema definitions within the VE Cooperation Layer.

However, in order to support other kinds of VE scenarios, the federated schema architecture of the DIMS could be extended to support the negotiation and sharing of different integrated schema definitions among VE enterprise members. For example, this feature would support VE collaborations in the product engineering sector in which small groups of enterprises need to negotiate and agree on the particular schema definitions involved in the technical design of a given product. In this case, enterprises first need to work together in order to unify their data models towards the definition of multilaterally agreed integrated schemas.

To support the definition of multiple integrated schemas among VE members within the federated DIMS architecture, it is necessary to design a data manipulation language that would allow the derivation of export schemas from local schemas, and the definition of integrated schemas from export/local schemas. For example, the definition/derivation language specifications that have been developed at the CO-IM group of the University of Amsterdam for the PEER federated database system, could be adapted to a federated database architecture for VE support [17, 5, 15, 16]. Alternatively, a general ODMG-based approach could be followed in which ODL and OQL languages are used for the specification of the definition/derivation language [50]. In this case, different types of federated schemas could be represented in ODL, and the derivation language could be based on OQL for data selection/projection operations.

Finally, the application of schema "mediator" components, which can help end

users with the definition of the specific VE database schemas, can be evaluated. In other words, intelligent database schema mediators could assist or even automate certain global schema definition tasks. For example, in the NIIIP project a VE *mediated* global schema is handled, through which conflicts between structural and semantic representations are resolved at run time [114].

### 6.3.2 XML for VE Federated Information Management in VEs

The role that XML can play as a standard format to support the sharing and exchange of data and metadata between the DIMS component and the internal enterprise systems needs to be further investigated. Furthermore, XML can also be applied to support certain federated information management functionalities. For example:

- The local schema at every DIMS node could represent and manage XML documents directly.
- The definition of DIMS export schemas could be based on XML documents.
- The export schemas represented as XML may be merged into an integrated schema, using some kind of definition/derivation language extensions. For instance, the use of XML to support database views has been addressed in [1, 2].
- When an export schema is queried through the federated integrated schema, the result of the subqueries may be represented and sent back as XML documents. This can facilitate the data processing tasks of Web-based client applications.
- The XML metadata may be used to cope with some schema integration problems associated with local schema heterogeneity issues, as explained in Section 6.3.1.

Please also notice that the use of XML is complementary to an interoperability approach based on schema integration using data definition/derivation languages. In other words, the combination of both approaches could be possible. The advantage of XML is that it does not really make assumptions about database models and it would properly support a "document-based" information management approach, such as the OAG proposal described in Chapter 2. In fact, the issue of combining "document-based" approaches, with approaches that rely on generic database interoperability architectures is also a challenging point. For instance, the application of document-based approaches for enterprise data exchange within the DIMS federated database architecture needs to be further studied.

### 6.3.3 Generic Federated Information Management for IDFs

Interchange Data Formats (IDFs) comprise all those standards aiming at the exchange of data among different enterprises. For instance, EDI and STEP standards, enterprise document models, and some XML document definitions could be considered as IDFs. Multiple IDFs formats may need to be handled within a given VE platform to support different functionalities in the same way in which for example, PRODNET

VCL supports EDI messages and STEP files. It is clear that data associated to different IDFs needs to be managed by the DIMS of the VE Cooperation Layer. Here, the challenge is to design a common data access mechanism for the DIMS in order to support as many IDFs as possible in the most flexible and generic way. Many of these formats are based on metadata schema definitions, and on the exchange of data values that comply with a subset of the metadata schema. Therefore, it remains to be evaluated if these requirements can be well supported within a general federated IDFs management framework for the VE Cooperation Layer.

Another important issue is the fact that despite the use of different IDFs, the access rights and visibility levels among the VE member enterprises still need to be defined and reinforced, and most of the IDFs management tools do not properly support this feature. Thus, by representing and storing the IDF information within a federated database management system, the IDF "documents" that are exchanged among enterprises can be better secured and protected. Finally, considering that most of the IDFs documents can be represented in XML, the idea of building an XML database with federated capabilities seems attractive, as described in Section 6.3.2.

### 6.3.4 Other Future Directions

Besides the main lines of research described in the previous section, there are several other important points for extensions and future directions that are briefly enumerated below (most of them have been addressed in previous chapters of this thesis):

- Active/federated database capabilities for advanced workflow management support. The objective of this subject is to analyze the application of active database concepts within a federated database architecture in order to provide an elegant and general support for the workflow management component of the VE Cooperation Layer. For instance, given the advantages of the definition of an information management and coordination kernel in PRODNET (constituted by the DIMS and LCM modules), the extended support that an "active" federated database management system can provide for workflow management engines needs to be further investigated. Namely, rules stored and managed by an active database system can be a useful mechanism to support the control and the data exchange among workflow management activities. For some examples of the use of active database rules to support workflow management, see [168].

- Incorporation of high-performance distributed computing services. As described in Chapter 2, some VE collaborative scenarios may demand an information management platform able to handle extremely large data collections that need to be accessed by geographically distributed users running computationally intensive processes. In this kind of scenarios, the incorporation of a high-performance distributed resource and data management services such as the Data Grid services, can be considered for the DIMS [26].

- Distributed transaction management functionalities. As mentioned in Chapter 2, for some VE infrastructures, there is a prominent need to support advanced *distributed* transaction management mechanisms [176, 114]. This need

was not relevant to the kind of VE scenarios addressed in this thesis. However, the DIMS architecture could be extended with these functionalities in order to be applied in other VE domains such as concurrent engineering, or to support advanced distributed workflow management requirements.

- Further development of Internet directory management functionalities. In Chapters 2 and 3, the need for directories of public information related to VE collaborations was identified. For example, for every enterprise it would be convenient to keep a directory of information describing the company profile and the role that it would like to take in potential VEs. This information would be made available for all other nodes in the network. The support for this kind of directories was certainly considered as a functional requirement for DIMS, although it was not fully included in the final DIMS implementation in PRODNET (mainly because it was outside the scope of the project). However, several advanced directory management functionalities were developed as an extension to the DIMS architecture, regarding common "interface definitions catalogues" such as the Service Interface Definitions Catalogue for VEs in the tourism sector (see Chapter 6). In general, other directory management functionalities can be incorporated into the current DIMS platform implementation.

- Design and development of generic Internet client applications and tools to support federated access to VE-related information. As mentioned in Chapter 2, the development of Internet client applications and tools to access data stored in the DIMS was not strictly mandatory in PRODNET, mainly because the reference VE Cooperation Layer was conceived to be installed locally at each enterprise, and therefore the VE information is accessed by end users and applications through specific DIMS services installed in the local VE node. However, in other VE application domains, Internet technologies and related standards such as Java, Jini, and XML, can be incorporated into the DIMS architecture to have access to VE-related information, as illustrated in Chapter 6. Other Web-based client applications supporting federated access to VE distributed information, can be added to the DIMS architecture in the future.

- Automatic Creation of Enterprise Export Schemas. In Chapter 4, some research directions were described regarding possible extensions to the DIMS Export Schema Management functionalities, such as the introduction of export schema templates and the automatic creation of enterprise export schemas. These extensions would facilitate to a great extent the task of defining individual export schemas on local enterprise information for every other VE partner.

Finally, it is foreseen that the research work regarding the federated information management approach presented in this thesis, will be extended and used in the near future to support virtual collaboration scenarios in other application domains, including VEs in agri-business and tourism sectors, virtual scientific laboratories, and distributed supply chain management.