Dynamic data sharing and security in a collaborative product definition management system

Kamel Rouibah*, Samia Ould-Ali

Department of Quantitative Methods & Information systems, College of Business Administration, Kuwait University, P.O. Box 5486, Safat 13055, Kuwait

Received 3 May 2005; received in revised form 23 January 2006; accepted 9 February 2006

Abstract

Product definition management (PDM) is a system that supports management of both engineering data and the product development process during the total product life cycle. The formation of a virtual enterprise is becoming a growing trend, and vendors of PDM systems have recently developed a new generation of PDM systems called collaborative product definition management (cPDM). This paper presents the concept of a virtual engineering community (VEC) to support concurrent product development within geographically distributed partners. A previous case study has shown that collaborative engineering design may be modelled from a parameter perspective [1]. Effective implementation of the parameter approach raises the following problems: how to support data sharing and secure that span the partner borders. This paper describes the system architecture, deployed security mechanisms, the prototype developed within cPDM, and the system demonstration using a real test. The implementation of this architecture extends a common commercial PDM system (Axalan™) and utilizes standard software to create a security framework for the involved resources. Collaboration infrastructure, shared team spaces and shared resources are essential to enable virtual teams to work together. Various organizational and technical challenges are implied. The outlined architecture features a federated data approach. These issues are discussed and potential perspectives in the area of collaboration engineering are identified.

*Corresponding author.
E-mail address: krouibah@cba.edu.kw (K. Rouibah).

Keywords: Parameter-based collaboration; Concurrent engineering; PDM; CPDM; Virtual engineering community; Common workspace; Web-based application; Virtual engineering community

1. Introduction

Complex product development is characterized by an enormous quantity of engineering data, process uncertainty, frequent engineering changes and disturbances [1]. Many iterations are due because of its iterative nature and multiple levels of data maturity. Efficient management of product engineering data is critical to the enhancement of corporate effectiveness [2]. Accordingly, companies are seeking techniques and tools that will allow them to control design, engineering and measuring through collaboration technologies [3]. Product data management (PDM) technology is increasingly becoming a necessity to manage complex engineering data. PDM is a system that supports management of both engineering data (such as drawings, project plans and part files) and the product development process during the total product life cycle. There are several benefits of PDM systems that have been discussed previously [4,5]. These include interdisciplinary collaboration, reduction of product development cycle time as well as reduction of complexity of accessing the information, improvement of project management, and improvement of collaboration in the supply chain [6].

Since its establishment during the 1980s, the concept of PDM has evolved [7]. In the mid-1990s, extended enterprises have been adopted as a manufacturing strategy where OEMs are working closely with their partners, supplier and customers. As a consequence the PDM concept was broadened to include the full product definition life cycle. As such, new tools started to emerge to support collaboration product development among the geographically distributed partners. With the Internet being used in new product development and its benefits...
widely recognized [8], the PDM concept was expanded to encompass new names such as collaborative product definition management (cPDM), collaborative product commerce (CPC) and product lifecycle management (PLM) [7]. All these concepts emphasize world collaboration using Internet technologies. A PDM system may include several functions\(^1\): document management, product structure management, workflow management, product classification, configuration management, process modelling, visualization and collaboration, web integration, security and interoperability. Such capabilities vary among suppliers of such systems and several problems exist while adopting and implementing PDM in organizations. In general, IT support for distributed virtual enterprise has been an extensive research area over a decade [10]. Dynamic data sharing and security within a virtual engineering community (VEC) are the central focus of this paper because experts of consulting PDM companies [3] require that for effective collaboration between partners (manufacturers, suppliers, engineering) product data must be accessible and comprehensible to people with varying skills and expertise and product data must also remain secure, yet be readily accessible.

This paper defines a VEC as a dynamic network created by at least two independent organizations in order to jointly design a new product (or enhance an existing one), or deliver a service without establishing a legal body on its own. The VEC has no common processes and procedures (e.g. approval and change procedures) and has no common IT-platforms for communication and exchange of information. Moreover, each VEC is built on a project-by-project basis with different partners, privileges, and duties.

For collaboration purposes, engineering data need to be shared at several points in time to ensure data consistency. In an ideal case, specifications for a product component would be mature right from the beginning and design delivered by each partner fits perfectly into the final product. However, practice shows that such a case never occurs and design is accompanied by many engineering changes [11]. Papers dealing with it are lacking in the case of cross-company collaboration [12][13]. Engineering changes are required for several reasons including change in customer demands or design errors due to involvement of several designers with different interests. Management of engineering changes raises the need to create and share a common view of product data that are relevant to all partners in the VEC in order to minimize their number and their impact.

Since design is performed in parallel, concurrent engineering principles force partners to ease the collaboration through the following requirements:

(a) extensively share data needed for design cooperation and hosted by different partners;
(b) provide location transparency, i.e. system supplying a user of the VEC with request data, and users do not need to know at which site those data are located;
(c) provide easy access to product data of the business partners if granted;
(d) require a notification service to inform users of the VEC about design progress and its problems; and
(e) monitor the progress being made towards the design objectives.

To tackle the issues “collaboration in a distributed environment” and “dynamic data sharing and security”, this paper describes the concept of common workspace and its implementation within a cPDM to support a VEC as described in the SIMNET project.

This paper is structured as follows: Section 2 discusses the background of the research. Section 3 introduces the framework including the collaborative distributed workspace concept and its requirements. Section 4 discusses the proposed architecture. Section 5 describes the prototype. Finally, the paper concludes by pointing out the limitations of the system and discusses future directions for research.

2. Background and literature review

2.1. Simnet framework

This research is a part of the Esprit Project SIMNET (EP 26780). This project aims to create an IT infrastructure for a VEC that is based on the parameter-based-collaboration approach (PBC), and to support cross-company engineering processes management. The solution investigated by SIMNET includes the four following elements:

1. An engineering workflow \((\text{ewf})\) approach to support parameters upgrading.
2. An engineering change management \((\text{ECM})\) procedure that links product structure to workflow management and support parameter change propagation.
3. Extensions of the PDM Axalam\(^\text{TM}\) system to support collaboration and dynamic data sharing within a community of partners.
4. A provision of a secured communication infrastructure to secure the exchange of product data within the VEC.

SIMNET approach \((\text{ewf} \; \text{and ECM})\) is represented in Fig. 1. The PBC addresses the need for better communication within a VEC. This approach emerged from a previous case study conducted within two European companies [1]. The case study has shown that engineers tend not to view their work in terms of creating documents, nor in terms of processes, but in terms of assigning values to parameters as well as affecting relationships among parameters. The \text{ewf} approach has been developed to structure the collaboration from the parameter perspective, for more details see Rouibah and Caskey [14]. \text{ewf} links engineering activities...
through decisions about basic engineering attributes (termed here as parameters). The relationships between these parameters and the people working with them capture the evolution of the design project. The ewf approach describes complex product development as a form of parameter processing. The engineering process is, therefore, approached as a network of activities that uses and produces parameters. The ewf consists of administrative workflow (i.e. predefined processes) as well as adhoc workflow (i.e. processes that cannot be defined prior to their execution). The ewf is used to upgrade parameters, i.e. specify values to parameters as design evolves. This evolution is based upon a single administrative process “the parameter approval and release workflow” as well as the use of the hardness grade concept (noted HG). The parameter approval and release workflow constitute the parameter life cycle, and involves six activities which are successively “predefined, un-worked, in-work, in approval, in release and released” (see Fig. 1). The HG concept refers to a description of parameter maturity, i.e. quality and reliability measurements of a parameter specification during the design process. During product design, engineering data exist in multiple levels of maturity within different departments and within different companies when product development involves more than one company. The case study of SIMNET [1] quantified maturity with numerical hardness grades from HG 1 to HG 5 (see Fig. 1). These grades reflect value certainty, for example, HG 1 may relate to a parameter having an estimated value with an open range, while HG 5 relates to an exact value with final tolerances. The ewf is used to upgrade parameters during their life cycle as well as within the five HGs (see Fig. 1). The adhoc workflow is used to notify user designers about pending activities. It is based on the relationship established between parameters, product structure items (element of bill of material), documents (requirements for design) and people who are assigned to parameters. In SIMNET, individuals in charge of parameters were specified and five role categories were defined and associated with the parameter life cycle. Ewf application requires initiating a joint project between partners of a community as well as defining a project container, i.e. a project that holds a set of parameters for collaborative engineering. The relationships between parameters, people, product structure and documents are also used by the engineering change management (ECM) approach.
developed in the SIMNET project (for more details see [12]). This approach is used to propagate parameter changes over the parameter network (Fig. 1) where there is a request for parameter change. This takes place once a parameter reaches HG 5 and someone requests a parameter change. In this case, two additional activities take place: “in change” and “revised”. This consists of moving through several steps:

- define interface parameters, i.e. parameters that are jointly defined by the partners in the VEC;
- create the parameter network (i.e. a structure of parameter and their relationships—see Fig. 1);
- identify parameters requiring changes;
- propagate the change by auditing parameters directly and indirectly affected (i.e. identify first degree linked parameter, second degree, ..., nth degree, etc.);
- discuss the parameters affected by reporting the change to others who may have interest;
- identify a list of parameters that need changes (including those affected from first degree, second, ..., nth degree);
- apply a joint approval and release workflow for the parameter list; and
- record the change for historical reference.

Accordinly, if there is any change in any product item, a notification service is launched and the ECM approach is used to propagate the change.

This paper focuses on the third and fourth objectives of SIMNET. While the PBC solves the process view of the distributed product development, it does not, however, address questions related to how to dynamically share and secure product data in a way to avoid their inconsistency and duplication. We concentrate on these two issues for two main reasons:

First, dynamic data sharing in a controlled manner is an important issue in collaborative design [13]. The purpose is to deliver timely information to the needed person [16]. Indeed, it is commonly shown in product development publications that a very high percentage of engineering hours is spent on organizational matters rather than on what engineers’ or product designers’ view as productive tasks [14,17]. Accordingly, frequent engineering changes consume much engineering time [11,12]. Also, it is believed that 70–80% of manufacturing is determined by design [18]. In addition, it is reported that 40–80% of all quality problems are due to poor design [18]. One of the remedies is to share information between people inside and outside partners.

Second, protecting those participants in product collaboration is a key issue since data could be misappropriated by hackers or corporate spies [19,20]. Security risks are becoming a serious problem for security management [21,22]. Dinnie [23] conducted a survey with 4254 companies in 29 countries about perceived barriers in adopting e-commerce in USA and Australia. Results indicated that security concerns ranked first both by American and Australian respondents. A recent study conducted with 8100 IT professionals in 62 countries revealed that information security budget accounts 11% of the total IT budget [24]. The study also revealed that 32% of respondents reported that they experience 5 hs downtime and 23% reported $500000 financial losses. The most frequently listed source of attack was hackers (66%). Security and trust are linked with each other, in that increase of security of data exchanged across company borders will lead to increased level of trust between partners.

2.2. Limits of PDM axalanT™

This paper aims to extend the functionality of an existing PDM system axalanT™. This has been selected for this study for three main reasons. First, Eigner & Partner is an active member of the European project SIMNET, and it is the owner of the PDM product AxalanT™. Second, AxalanT™ is used by two end-users within SIMNET. These are SGP and Knorr where the PBC approach has emerged. Third, Eigner & Partner (EP) aimed to enhance their PDM system in order to be among the proactive PDM firms. Besides, the PDM of AxalanT™ has limits with regards to workflow capabilities. The workflow module does not have a facility to generate graphical workflow process definitions. AxalanT™ was able to represent workflows process only with linear sequence of activities. It features only one type of activity, the standard “activity”. Modern complex business processes require adding the logic of control flow such as in a situation involving synchronization or choice (OR/AND split). Moreover, workflow definitions are stored as a sequence of activities. Each activity has its own resources expressed either by “users”, “groups of users” or “distribution list”. The role concept, however, is missing.

2.3. Related work: PDM systems

The two problems (data sharing and security) addressed in this paper did not receive the due attention from previous research in the PDM literature. Similar problems have been investigated by VIDOP project [25–27]. Over the last decade, PDM literature has addressed several issues including methods to design PDM web-based [28], problems and issues related to PDM implementation [5][29] description of specific PDM systems [30], guideline for PDM implementation [29], identification of strategic components of PDM systems [9], and the integration of workflow and PDM systems [2,31] collaboration through visualization [3]. Other authors do mention limits of PDM

---

1Eigner and Partner does not exist any more. Eigner was acquired by its competitor Agile Inc (www.agile.com).

Visualization systems used in product design where excluded from this review.
functions such as security functions within distributed PDM systems [20], inter-organizational and concurrent workflow [32], distributed engineering change management for concurrent engineering [14,33], lack of dynamic data sharing [15], and inexistence of a generic standard for PDM system implementation [34]. According to Gao et al. [34], the real problem is to define a standard structure to exchange data/knowledge that is not yet solved. Gao et al. [34] proposed a model integration that is STEP based. STEP is a standard used to exchange product data between different engineering systems [35]. Other authors, such as Yeh and You [36], raised issues related to system integration and data sharing between heterogeneous systems. Since PDM systems have been developed according to different paradigms, the focus was on data integration/interoperability rather than on dynamic data sharing. PDM interoperability could be achieved through: (a) the use of proprietary applications and protocol [32,34,37]; (b) the use of STEP standards [34,36]; and (c) the use of UML [38]. Unlike the PDM, WI MS interoperability may be achieved through other standards such as WfMC [39]. It is a standard used to exchange workflow data between workflow systems. Outside the PDM field, other initiatives to overcome system interoperability and integration emerged after the SIMNET project and, therefore, were left out.

2.4. Recently related work: dynamic data sharing

It has been reported that the benefit of information sharing is significant [40] and substantial studies were done in the area of supply chain [40,41]. Others [43] investigated sharing of quality information, while Chen [42] focused on modes of information sharing (full sharing vs no sharing). Other authors questioned “what is the most appropriate IT/IS solution to information sharing” [40].

In the engineering area, data sharing received much attention and expressed itself through a different focus including Computer Supported Collaborative Work (CSCW) [44]. For example, Salhieh et al. [45] discussed specific CSCW support types in the area of engineering as well as their benefits. However, in the modern engineering area, data sharing has been expressed through different names including co-design and concurrent engineering. Co-design refers to collocating a multidisciplinary design team to carry out a complex design task through effective communication and collaboration. Research and development in this field is active and a number of software systems and methodologies have been developed (see, for example, [32]). Several popular systems are available for real co-design such as CoCreate [46]. Such systems usually consist of four kinds of components: team management, distributed part and assembly modeller, repository and messaging. In the team management component, collabora-

---

utilizing the services of the common workspace, team members can view the evolving product information and be notified in case of engineering changes made by others. The workspace is used to publish a collection of useful data (parameters and associated objects) that support cooperation in a controlled manner. The workspace solves data management problems (e.g. data inconsistency, data isolation and data redundancy). Partners are able to navigate through the published data in a way that is independent from its current location. Detailed information about a node can be retrieved by following the link to the remote object in the partners’ system. Therefore, the workspace allows integrating different external systems hosted by VEC partners. Nodes are also used to direct communication between partners through the workflow and notification service (Fig. 2) if there is a change. Fig. 2 shows joint product design between two companies. The main-contractor “A” and its supplier “B” are jointly involved in a new project. The product interface is represented by the six nodes in the workspace. Nodes 1–3 are under the control of “A”, while nodes 4–6 are under the control of “B”. All six nodes are linked to real objects under the control of “A” and “B”. Different workspaces could be generated for other projects that involve different partners and suppliers.

Table 1
Two systems architecture for co-design with distribute co-modelling function (adapted from Li et al. [32])

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Functional description</th>
<th>Illustration diagrams</th>
<th>R&amp;D example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelling client/ communication server</td>
<td>Clients are equipped with whole CAD/PDM systems and some communication facilitators</td>
<td>CAD system-facilitators</td>
<td>Pahng et al. [47]</td>
</tr>
<tr>
<td>Manipulation client/ modelling workspace</td>
<td>The data structures in clients are light-weighed, and they primarily support visualization and manipulation functions</td>
<td>OneSpace [46]</td>
<td>Li et al. [32]</td>
</tr>
</tbody>
</table>

Table 2
Other related work of distributed concurrent engineering for design and manufacturing

<table>
<thead>
<tr>
<th>R&amp;D Work</th>
<th>Key characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chen and Liang [49]</td>
<td>A system integrating and sharing engineering information to support CE activities such as domain investigation, functional requirement analysis, and system design and modelling</td>
</tr>
<tr>
<td>Zhao et al. [50]</td>
<td>A system for product information exchange and sharing among distributed CAD/CAM users with different platforms</td>
</tr>
<tr>
<td>Nidamarthi et al. [51]</td>
<td>Designers upload and download their CAD files in a server for sharing and exchanging data</td>
</tr>
<tr>
<td>Huang [52]</td>
<td>The main modelling activities are carried out in a common workplace in the server side</td>
</tr>
</tbody>
</table>
3.2. Requirements of the common workspace

Product data sharing across company borders strikes a very sensitive area, and several requirements are, therefore, required:

1. **Workspace management requirements.** It includes management of structure (nodes and relations) such as the creation, modification, viewing and deletion as well as the management of links to remote objects. Links to remote objects are established via URL, and a graphical browser is required to view the node structure.

2. **Workflow management requirements.** For the VEC purpose, a distributed workflow model is required to model and execute shared processes. Such workflow model has the four elements (Fig. 3): activities, roles, messages and objects. **Activities** are elementary tasks in the shared processes. There are two kinds of key processes in SIMNET. An evf process is related to parameter creation, dissemination, approval and release before the design reaches HG 5. It involves six activities (statuses) predefined, un-worked, in-work, in approval, in release and released. “Predefined” is a parameter whose value is specified by the final customers (e.g. limit of the train should be 180 KM/H). **Un-worked** is a parameter whose value is not yet specified but will be specified, checked, approved and released. “In work” is a parameter whose value is under construction (preliminary estimation) or is still in specification and check. However, it is neither approved nor released. “In approval” is a parameter whose value has been estimated and needs to be fixed. “In release” is a parameter whose value has been estimated and fixed. “Released” is a parameter whose value has been accepted by all parties. Activities associated with these statuses consist of moving a parameter from a current status to another one (see Fig. 1). An ECM process is used to update parameter values once they are released by the VEC community (once parameter reaches HG 5). It involves two activities: in change and revised. In change refers to a parameter for which a request for change has been initiated, studied, and accepted after a design has been released and HG 5. Revised refers to a parameter whose value has been accepted once an agreement is reached among involved parties. A process modelling system is also required to formally specify processes. A graphical language can better help to generate, analyse processes by visualizing their structure. **Roles** are associated with parameters evolution. SIMNET defines five roles: coordinator, collaborator, reviewer, subscriber, and supervisor. **Messages** (through a notification mechanism) are...
required to: (1) initiate approval and release procedures across company borders, and (2) to keep people informed about updated nodes. The notification could be based on XML messages that can be interpreted by the workspace and the PDM systems. Objects are data which are shared among the members of the community. They are mainly the parameters and data managed by the PDM systems (such as CAD drawings or product structure).

3. Security requirements. Access to local data is managed by the individual partners who are the owner of their data while access to the workspace is managed by a management entity (ME, Fig. 3). Security of distributed workspace requires online transactions as well as offline (e.g. e-mail) message exchanges. Since security solutions must contribute to the effective development of trust, both at each individual partner as well as at the level of the VEC, security issues regarding the common workspace include: authentication, authorization, confidentiality, integrity and non-repudiation.

4. Other requirements include system integration and administrative functions. System integration refers to the integration nodes in the workspace to remote objects under the control of VEC partners. This includes system class, name, vendor and version. Administrative functions also include project management, users’ management involvement in a specific collaborative project, communication procedure as well as possibilities to assign users from company “A” to access limited data of company “B” and vice versa.

The next section specifies the SIMNET workspace architecture.

4. Architecture of the SIMNET workspace

4.1. Architecture components

The major components of the workspace architecture are represented in Fig. 4. This architecture is based on the PDM system Axalant™. Architecture is split in two parts: the workspace service and the workspace browser.

4.2. Workspace service

The workspace service includes structure management and integration facility.

Structure management consists of the element classification and the basic structure management. The element classification also includes structure rules. It is a component that has the function to define which particular compositions of nodes and their associations are permitted. Both nodes and their relations have attributes. The basic structure management function is used to generate diagrams in the common workspace. A diagram is a graphical representation of a structure that is made of nodes and
relations between nodes. A diagram is created, displayed and edited with the help of a specific browser. All information about diagrams, nodes, relations, attributes, associated files and URL are stored in the workspace structure repository of Axalant™.

The Integration facility allows to access data from external systems through any application program interface (API) as well as integrating Axalant™ applications (e.g. parameter management and parameter change management). The flexibility is achieved through an integration abstraction layer. It provides a standardized access method to integrate systems into the common workspace. Information about an integrated system is stored into the integration repository. This repository contains general information about external systems of a particular type, data about objects related to nodes in the workspace as well as an integration logic. Integration logic has two levels. System integration enables access to data and functionality of a specific system. Data integration consists of integrating data (e.g. parameters or documents) out of a system into the common workspace.

4.3. Workspace browser

The workspace browser allows users to work interactively with the structures or diagrams. The goal is to provide a user-friendly interface that allows an easy and fast access to the structure and the system functionality. There are two types of browsers; Axalant™ native clients and non-native clients reflecting different situations where partner use or not the PDM system Axalant™.

4.4. Communication between “workspace browser” and “workspace service”

The workspace browser is implemented in Java, which allows both Axalant™ clients and not native clients to access it. The integration into the workspace is based on a framework provided by the Axalant™ Java client. The communication with the workspace service uses the external communication interface (ECI), an Eigner Partner proprietary API. The ECI is based on an inter-process communication where the workspace browser acts as a client, and applications build with Axalant™ act as the server.

The architecture of the common workspace provides a framework for abstraction of the integration systems. Integration requires linking heterogeneous systems (e.g. PDM and CAD systems) under the control of different partners. Each system includes different objects such as documents and parameters. These objects will be assigned to a workspace node that we refer to by object nodes. Independent of the source system class (e.g. class of PDM system or class of CAx—Computer Aided x-applications) and the source system object class (class of objects from the external system to be viewed and linked to the workspace, e.g. class of parameters) the workspace integrates any new system the same way using three LogiView (procedure developed in Axalant™) procedures:

- **System installation procedure** is called to select and set up a new system (e.g. add the PDM system Axalant™ to the workspace).
- **Object view procedure** is called to view an object that will be assigned to an object node in the workspace (e.g. view a parameter “axle-diameter” under a company “A” before to be added to the workspace).
- **Assign object procedure** is called to assign an object to an object node (e.g. assign “axle-diameter” to a node in the workspace).

In order to fulfil the security requirements of all VEC partners, an extranet solution that ensures security of the workspace is described in the next section.

4.5. The security mechanism

The security mechanism as developed in the SIMNET project ensures online transactions (with interactivity) and offline message exchanges (non-interactivity). Online refers to the case when a user (e.g. from SGP) uses a web browser (e.g. Internet Explorer) or a client program to interact with the SIMNET application server (represented respectively by number 2 and 3 in Fig. 5) and the user gets immediate feedback. Offline refers to the case when a user (e.g. from Knorr) uses standard e-mail (e.g. Outlook) to dispatch information to VEC users (represented by number 1 in Fig. 5). In this case, when using message exchange, the user gets feedback with considerable delay. The deployed security mechanism is based upon CLAVISTM, a full strength security framework designed and developed by Mission Critical [55], a partner within the SIMNET project. This infrastructure includes state of the art standards such as public key infrastructure (PKI), transport layer security (TLS) for online interaction and secure multipurpose internet mail extensions (S/MIME) for offline communication (e-mail), as well as a certificate server, integrated with a LDAP (Lightweight Directory Access Protocol) server.

![Fig. 5. Security architecture for the common workspace.](image-url)
All VEC partners are peers (i.e. any member can be a service provider or a client of a service), with the exception of a service provider or a client of a service), with the exception of a management entity (ME). The ME is independent from any single organization and is trusted by all members of the VEC. The ME role consists of implementing the security policies decided by the community, while preserving the autonomy of the members. The ME is also the certification authority (CA). It is a trusted organization that performs authentication, certificate distribution and key management. Key management includes certificate issuance, revocation, suspension and renewal. ME also manages the Certification Authority Server that issues and manages certificates. ME issues certificates on behalf of the organizations, through the local registration authority (LRAs) within each organization. Tasks performed by a LRA include reception of certificate applications, confirmation of identity information, assignment of unique names to subscribers, and acceptance of renewal requests. However, the LRA does not perform any key management functions. ME also controls memberships as well as access to specific service in the workspace through the Login and Access Server and the Directory Server. The Directory Server is used to manage three items. First, it is used to locate organizations in the VEC, grant access to authenticated users (e.g. roles and privileges within the VEC) and resources within the workspace (such as Axalant servers). The directory server also stores public keys related to users' certificates within the VEC. Finally, the Directory Server stores the Access Control List required for the authorization service (such as specification, validation or approval and release of a parameter value).

The authentication process based on ME involves three phases. First, a user must be recognized as a valid member of the VEC, having the right to access the services of the community. This can be considered as a logon service to the whole community. Second, when the user is recognized as a valid member of the community, his access rights must be controlled. While such a user could have access to a specific service of a certain enterprise, he could be denied access to other services provided by the same enterprise. This can be considered as an access service. Third, the user sends and receives encrypted information.

The workspace hosts application services used by users of the VEC. In such a way, any authenticated user can interact with the services (e.g. parameter management or parameter approval and release) in a secure way through asynchronous or synchronous transmission modes.

The next section illustrates the collaborative mechanism.

4.6. Collaborative mechanism

The process of collaborative parameter specification in the system is depicted in Fig. 6. In the collaborative server, a working session can be dynamically created and accessed by clients (users) of different partners. Users using clients can carry out collaborative design activities and can play different roles and take on different responsibilities. For
example, a designer may be primarily in charge of decisions regarding a particular parameter value, but also be consulted about other parameter/component values that influence this decision.

A design process starts when a supervisor instantiates a project container. The parameters of the project are identified in “un-worked” status. All these parameters must pass from un-worked to released status as they move from their initial (HG 1) to final hardness grade (HG 5). Such upgrading is controlled by a workflow that involves six activities. The five roles in Fig. 6 are resources for this workflow and are used to control design output from different perspectives.

1. The Supervisor opens a session and requests collaborators to specify parameter values under their control.
2. The collaborator accesses the system where data are stored.
3. The system authenticates the collaborator.
4. The collaborator selects and accesses a parameter with status “un-worked” and assigns a parameter range value (minimum and maximum).
5. The workspace server alters the status to reflect that it is now actively being worked upon, sets the parameter in status “in-work”, and assigns the lowest level of the maturity indicator (HG 1); then, the workspace server generates automatic messages to coordinators in the engineering functions and asks them to contribute to fix it (either to agree about its value or to request change).
6. Once they agree, the parameter is promoted in status “in approval”, and the system generates messages to “reviewers” and “subscribers” from other business functions such as manufacturing and marketing who may express interest to the parameter. Product manufacturability could be the reason of people participation from manufacturing department.
7. Once an agreement is reached among all the five roles involved in the collaborative design, the workspace server compares different value ranges, generate the common consensus range value, and sets the parameter in status “in release”.
8. The supervisor checks whether all the objections have been dealt with and taken into consideration, then he sets the parameter in status “released”.
9. In case there is a request for a parameter change after it has been frozen, the supervisor requests collaborators and coordinators to study the request. In case it is accepted, the parameter is set in status “in change” and the workspace server sends automatic message to all five roles.
10. The same process is then re-iterated and the system maintains versions of parameters. Users affected by such a change need to study the potential impact of the change on parameters under their control—including the first and second link parameters. Each user will then create a list of affected parameters. A collective workflow process is then initiated for such a parameter. This process is well described previously [14].
11. The evolution of a parameter value through the HGs controls the design process. Figs. 1 and 7 show that two levels of HG (1 and 2) control the evolution of parameter within the system embodiment design, while HG 3 and 4 control such evolution in the component embodiment design. HG 5 is the case when the design is frozen and all objections raised by all involved parties have taken into consideration.

The above process is reiterated as long as the parameter maturity (or HG) is less than 5. Once the HG is 5, changes cannot occur unless an engineering request order is requested, studied and accepted.

In order to ease interaction between users who fulful different roles, the workspace is equipped with a discussion mechanism. Users can communicate in a group (e.g. using chat program) or one-to-one manner (e.g. using e-mail). If there is any change, each user will be informed by the system automatically through the discussion mechanism. In addition, all the above tasks assure the workspace has authenticated the users and has checked whether they are authorized for the services they use.
Understanding the previous collaborative mechanism, the next section illustrates the functionalities of the prototype.

4.7. Prototype achievement

A collaborative workspace prototype was developed based on the PDM system Axalant™ of EP. The workspace prototype complies with WfMC and STEP. These two standards are not discussed in this paper. The prototype includes the following modules:

1. parameter management module,
2. workflow module,
3. In workspace browser module,

4.7.1. Parameter management module

This module allows users to define and manage several items associated with the parameter based approach (see Fig. 8), such as parameter definitions, including parameter instance and types, default values, assigned roles, related items, documents and project containers, an inbox to access information provided by the notification service, and work items referring to approval procedures. Different management functions are used to maintain types and instances of parameters (e.g., create, update, modify, delete and add).

4.7.2. Workflow module

This module has been enhanced according to WfMC and STEP standards. Enhancements include the inclusion of the role concept. The new Axalant™ allows assigning resources to roles in order to execute activities. The usage of roles makes it possible to become independent of the assignment of specific users and/or groups and, therefore, contribute to the reduction of administration effort. Role concepts allow team management to perform complex administrative business processes that involve new activities such as split- and join-operations. In our case, it allows parameter specification, approval, validation and change. In the team management component, the collaboration mechanism and the team organism are specified. The collaboration mechanism consists of specifying the product items (BOM) that will be the subject of collaboration and what parameters are under control of each individual partner or a mutual control. The team organism consists of specifying the human resources that will be appointed to each role within each company. Enhancements also include the possibility of easing generation of graphical workflow definitions by click and drag. Such generation is now facilitated through a graphical workflow tool ProView that is integrated to Axalant™. ProView has been developed by PISA, a company based in Berlin and partly owned by EP since 1990. The two companies (PISA and E) have collaborated together since 1996. Axalant™ is now able to define and execute ad-hoc workflow.

4.7.3. The workspace browser module

This module enables people without a native Axalant™ client to participate in the parameter approval and release procedure. Different functions for viewing the current information are provided. Fig. 9 depicts a prototype implementation of the workspace browser. It allows users to create and visualize nodes, and attach a URL link from that node to a remote object under a partner control.
4.7.4. Notification mechanism module

This module allows linking the workspace Axalant™ with external e-mail systems (e.g. Microsoft Outlook and other chatting programs). This integration enables direct communication between users involved in collaborative design through sending e-mails directly from the workspace to relevant external recipients through the corresponding e-mail addresses in Axalant™. The company-specific e-mail system can be initiated from several Axalant™ modules: document, workflow, configuration management, project and items. For example, if any change occurs to any parameter, automatic messages are sent from the workspace server to notify subscribed users who may approve or reject design decisions. The notification e-mail contains a link to the relevant work items of their inbox. From there, the user is able to vote on the current issue.

4.8. An example

A scenario about collaborative design between the two partners SGP (the main contractor) and Knorr (a supplier) is shown in Fig. 10. This example shows how the workspace is used to notify partners about design changes. The two partners use the service of a workspace provider and a local PDM system (both Axalant™ but with different versions). Access to the workspace is managed by the ME who acts as application service provider. In order to access the workspace, all partners use the federation browser, the java Axalant™ client. The node creation is based upon the pull technology (i.e. a user requests information via a browser to create nodes and their relations), as well as to determine the URL to the remote objects, hosted by a partner in the VEC. During the kick-off, members of the VEC collectively define a new project, e.g. development of a new bogie for railway transport. The federation browser is used to nominate and appoint the project manager of the new project. The next step consists of jointly defining the work breakdown structure. This consists of splitting parts of the new product among VEC partners. In addition, users assuming the five roles and their privileges in charge of the PBC are appointed to the project within each partner. Later on, users with specific access rights have to define links between the nodes in the workspace and the remote objects (hosted by systems under their company control).

Let us assume that a user X from company SGP receives an e-mail requesting him to approve a specific parameter (Pi). Before approval, X may need to check additional information (e.g. check a product bogie item related to parameter (Pi) under the control of company Knorr). Fig. 11 shows the scenario to access the workspace and request services. First, the user contacts the SIMNET Logon and Access Server through his browser. This requires the user to unlock his private key by a password. When the user is authenticated by the Logon and Access Server as a valid member of the community, he is granted access. This allows him to browse the node structure (e.g. open the URL in his e-mail). The related node can be found if this object has been previously published in the workspace by Knorr. Second, if the Access Control List in the workspace grants him access to a specific service Si at the Knorr side, user X receives a token (a dynamic certificate) that is valid for a period of time (the default value is 24 h). With this token, user X is able to access the server of Knorr using a secure channel (with TLS). The Knorr server checks the identity of X through the local registration authority (LRA). In this case the information is retrieved from the Axalant™ server at Knorr side and passed back to the web browser at company Y (SGP). Changes to objects in the local databases (at Knorr side) are communicated directly between the local PDM server and the workspace server.
Now assume a change has been made on a parameter \( (P_j) \), under Knorr control, and which is represented as a node in the workspace. Assume also that user X is subscribed to that parameter. In that case the Axalant™ server at Knorr starts a parameter workflow change process and generates a message to the Axalant™ server of the workspace containing information about this change. The workspace server receives this message, links...
it to the corresponding node in the workspace and sets the parameter in status “in change”. After that, a message will be generated by the workspace server and sent to all users (including X) that subscribed previously to this node. Accordingly, user X will be notified in a synchronous way using the workspace push technology (i.e. a user receives in his mail box an e-mail without requesting it), and a message is passed automatically to his mailbox. The user X will study the possible impact of $P_j$ on parameters under his control. Possible impacts may include first (direct) and second (indirect) related parameters. Decisions of the user X include approval and validation of a list of potential parameters (first and second) that are or not affected by the parameter ($P_j$) change. Also, the five roles previously described may also react in the same way. The result is later transferred back as messages to the workspace server. The workspace then starts a collective approval and release workflow that has been described previously [12].

5. Test

The secured workspace has been tested in a real case. The purpose was to test how designers and engineers perceive the concepts and the prototype. A pilot phase was performed during six months. The test was performed on a specific project—a new railcar bogie design—SF3000 platform. The project involved two European companies: SGP (Siemens is the major shareholder in SGP) the main contractor responsible for the whole bogie design and Knorr (one of SGP’s suppliers) responsible for the design of magnetic brake system. The test was a real life exercise and not some simplistic simulation. Twelve people from SGP and two from Knorr participated in the pilot phase. During the pilot phase, many technical problems occurred and were reported by participants based on screenshots and additional comments. Most reports referred to the parameter management and the parameter-based approval and release workflow. These problems were solved in a short time and other problems that affected the Axalant™ workspace were also reported and solved with the support of EP. Two methods of collecting quantitative and qualitative data were used: survey questionnaire and semi-structured interview. The pilot test included SIMNET concepts (PBC, roles, hardness grade, ewf, parameter approval and release workflow, parameter change management) and implementation (prototype). Test results demonstrated the following:

- **Perceived usefulness of SIMNET concepts:** With regard to quantitative benefits in terms of reduced engineering hours and avoided costs, SIMNET methods and concepts were evaluated by the end-users as very helpful. Especially they help to assist in clarifying the current state of design activities, enabling the elaboration of corrective measures, and reducing engineering change costs. With regard to qualitative benefits, SIMNET concepts were seen in support of quality assurance and improved evidence in case of disputes. Substantial conceptual changes are required to support how parameter-based change management has to be performed as well as how change is done. According to the participants, real life change management turned out to be much more complex than initially thought during the SIMNET project.

- **Perceived usefulness of implementation:** The evaluation of the quality of implementation in general resulted in high rankings. An exception is the parameter-based change management functionality (which receive low ranking). The functionality of the web browser and the functionality for the parameter management received medium ranking. Results of the parameter-based change management functionality revealed a need for significant changes of the underlying procedures and methods.

6. Conclusion

This paper presented the distributed workspace concept. Such a concept is not new, but its application in the engineering area is promising for further research. The paper presents its implementation within the cPDM system Axalant™ as well as its security solution to facilitate sharing and securing data exchanges within a VEC. Strong security mechanisms, involving state-of-the-art standards, have been deployed to enforce data security in the workspace.

6.1. Main contribution of this work

This research has several contributions useful for both practical and research:

First, the most important is the development of a web-based workspace supporting collaboration in the engineering field. This workspace acts as a portal that connects heterogeneous systems (PDM and workflow systems) hosted by different partners and allows data sharing without losing the control on local data. It allows dispersed teams to carry out feature-based collaborative design activities based on the parameter approach across company borders. The system provides availability of the data that stays under the control of each VEC member while being shared without leading to data inconsistency and duplication. Accordingly, partners are able to track changes (who have edited a product data element and when, parameter version, and the history of change), regardless where the data are stored. While the PDM systems manage the engineering data (parameters), the workflow system supports the engineering processes of creating, discussing, updating, approving and releasing such data. Besides, the workspace involves a notification mechanism that contributes to shorten communication between partners and helps them resolve problems early in
the development lifecycle. This is an important contribution since few systems and studies report existence of a system dedicated to support management of engineering change across company borders. Moreover, the implemented solution provides authentication for both server and client.

Second, the design of an inter-organizational information system that involves customers and their main suppliers is a very complex task. The workspace’s functionalities were under continuous modification and refinement until the very end of the pilot phase at the SIMNET runtime. The test has also shown that senior managers consider engineering activities as a promising area where cost can be reduced because of the high cost associated with engineering changes. At the same time, senior managers perceive concurrent engineering change management across company borders a very complex process to handle. Therefore, rather than IT competencies, it is the support of strategic management level (at SGP) that constitutes the critical success factor for the achievement of inter-organizational information system success, especially for system that crosses company borders [56].

Third, cross company collaboration is not successful in all cases. In the case of SGP/EP, the relationship was extremely strong but was suddenly fragile as the company stopped using Axalant™. During the late stage of the SIMNET project and workspace implementation, the director’s board of Siemens transportation systems (Siemens is the major shareholder in SGP) decided to reject Axalant™ as their PDM solution in favour of Windchill (from PTC). This suggests that collaboration systems should be independent from specific PDM vendors.

6.2. Limits

There are technical problems in the current system that could be improved by future work. Moreover, our solution does not fully support collaboration in a multi-organization situation, as it was initially thought. Collaboration in such a way involves n:m servers interoperability and a chain of Certificate Authority (CA). Instead, our solution is 1:n server, since it is developed for a VEC that uses only one server of PDM system Axalant™ with different versions. For this purpose, we adopted an open PDM-workflow architecture in compliance with the WfMC and the STEP standards and extended the functionality of the Axalant™ environment to enable data sharing.

Besides the achievements, the architecture offers more functionality than has been realised in the workspace prototype. First, the implementation is dependent of a commercial PDM system (Axalant™). Enhancements done were focused more on the extension of the PDM Axalant™ to comply with requirements of PBC approach. Second, the PBC has emerged from a case study with two European companies [1], which limit generalisability of the results. Accordingly, fewer efforts have been spent on “collaborative engineering”; even the test shows this is a promising research area. Third, the prototype needs improvement. In particular, the user interface for engineering change management should be more design oriented in order to be accepted by the designer community. Further investigations such as graphics and tools to express and represent parameters’ constraints may constitute relative support for designers and avoid much of design iterations. In addition, the deployed solution is not a pure web. The client is HTTP based, but it is a Java-rich client. The notification service sends out a human-readable description that uses HTML templates. This offers good control for the e-mail layout that is simple to handle. This solution works and demonstrates the applicability of the concept. However, the solution did not work as was planned. The original plan was to have web-based client (a “light” client) to access the workspace, i.e. a pure HTML or DHTML (Dynamic HTML) client. This supposes that the server generates the corresponding HTLM (or DHTML) with techniques such as ASP (Active Server Pages), JSP (Java Server Pages) or direct generation by the server. Due to timing and resource constraints, it has been decided that it was not reasonable to base the prototype on a “pure” light client but a combination using a Java client.

6.3. Perspectives

As for future direction, this research proposes to overcome previous limits as well as the following.

First, this paper encourages pursuing the exploration of engineering collaboration in a multi-organizations (multi-servers interaction) in order to further knowledge about this field. Such objective could be approached through the combination of B2B, workflow and XML. Second, the authors also encourage continuing to test the system in order to answer the following question: does the approach (concept/prototype) improve user ability to perform design tasks and whether the product (design result/development) could become better?

Acknowledgements

The project to which the above-described results refer is co-funded by the European Commission under the ESPRIT programme (project No. 26780—SIMNET: Workflow Management for Simultaneous Engineering Networks). The author wishes to acknowledge the EC for its support and the project participants for their contribution.

References


