DESIGN AND VALIDATION OF AN INTERORGANIZATIONAL INFORMATION SYSTEM

Kamel Rouibah

Department of Quantitative Methods and Information Systems
College of Administrative Science, Kuwait University
P.O. Box 5486 Safat, 13055 Kuwait

ABSTRACT

This paper presents an interorganizational information system that aims to structure collaboration of engineering activities as well as data sharing across company borders. The paper also describes the approach underlying the system, validates it by designing a system prototype, and tests the system using questionnaire and in-depth interviews in order to further knowledge about the subject. The main results from the test show: collaboration engineering is potentially important for senior managers; end-users were specifically attracted more by the concept rather by its implementation; engineering change management is a complex process; and the support of strategic level is a critical success factor. In addition, the paper describes other factors that emerged during the ongoing project and inhibit success of the system.

Keywords: interorganizational information system, product data management, parameter based collaboration, perceived usefulness, design quality, prototype

INTRODUCTION

Complex product development is characterized by an enormous quantity of engineering data, process uncertainty, many iterations due to its iterative nature, and multiple levels of data maturity (Baldwin & Chung, 1995). Product design, therefore, does require changes. The ability of companies to better manage engineering processes as well as engineering changes can decrease cost, shorten development time, and produce higher quality products. Engineering changes refer to changes or modifications in form, representation, design, material, dimensions, and functions of a product or component after an initial engineering decision has been made (Huang & Mak, 1999). Recent studies conducted in manufacturing industries have reported that engineering changes involve cost and are a time consuming problem (Maull, Hughes, & Bennett, 1992; Boznak, 1993). Accordingly, companies use Product Data Management (PDM) systems to manage and reduce the complexity of their engineering data. A PDM is a system that supports management of the engineering data and the product development process during the whole product life cycle. PDM systems have several benefits that have been well discussed (Liu & Xu, 2001). As the product development was

expanded in 2000 with the widespread use of extended enterprise and use of Internet technologies, the PDM concept was expanded to encompass new names such as Product Life Cycle Management (www.cimdata.com). These new concepts aim to increase inter-company collaboration. A PDM system includes a variety of functions (Kim, Kang, Lee, & Yoo, 2001) such as document management, product structure management, workflow management, process modeling, support of collaboration security, and interoperability. Over the last decade, an increased focus was put on different issues. Among these are the following: methods to design PDM web-based (Chu & Fan, 1999), problems and issues related to PDM implementation (Siddiqui, Burns, & Backhouse, 2004), security requirements for distributed PDM system (Leong, Yu, & Lee, 2003), integration of workflow and PDM systems (Kumar & Midha, 2004), and system integration and data exchange between heterogeneous systems (Yeh & You, 2002). Despite these efforts, PDM systems do not provide adequate support for data sharing when collaboration spans company borders (Rouibah & Caskey, 2005).

Collaboration between companies require: (a) extensively sharing data that is needed for collaboration and hosted by different partners; (b) provide the location transparency (i.e., system supplying a user with request data, and the user 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 notify users about engineering changes; and (e) monitor the progress being made. With regard to the above requirements, existing frameworks are not satisfactory especially to support intercompany collaboration (Chen & Liang, 2000; Nidamarthi, Allen, & Sriram, 2001; Huang, 2002). For example, in the engineering field, engineering tasks are ad-hoc with unstructured processes.

This paper presents an interorganizational information system (IOIS) in the form of concept and PDM prototype. An IOIS is an information system that automates the flow of information across organizational boundaries and links a company to its supply chain (customer, distributors, or suppliers) (Bakos & Irvine, 1991). This IOIS aims to increase data sharing related to product and services between organizations independent of their locations. The role of IOIS is increasing. As companies are operating worldwide, and with the improvement in information technologies (IT), organizations are increasingly aware to develop and use IOIS (Johnston & Vitale, 1988; Bakos & Irvine, 1991; Wilson & Vlosky, 1998; Allen, Colligan, Finnie, & Kern, 2000; Shah, Goldstein, & Ward, 2002). However, most past efforts did focus solely on the development of IOIS to share order information, production information, and sales and marketing information between several companies. Studies that focus on development of IOIS in the area of product design are seldom, especially where there are a lot of engineering changes. If there is any change in any product items, it is hard to know who needs

to be informed and how to propagate the changes among people of the engineering community. With regard to this matter, existing research papers did focus on the subject within single companies (Huang & Mak, 1999; Kim et al., 2001; Maull et al., 1992).

To overcome the above drawbacks, this paper contributes to this field through the design of an IOIS. This aims to place the organization into a position of competitive advantage (Johnston & Vitale, 1988; Henderson & Venkatraman, 1993).

The IOIS was developed during the participation of the author in the Simultaneous Engineering Networks (SIMNET), a European Community (EC) project. This paper is structured as follows. The next section presents the research methodology. The section after presents the IOIS being developed (the underlined method and the prototype). The description of the test and the main results are then presented. Finally, this paper ends by summarizing the main findings and points out several issues related to the success of the IOIS efforts.

RESEARCH METHODOLOGY

The research method used in this article is an action research (Checkland & Holwell, 1998). This method consists of five steps. First, the researcher and practitioners define research questions "How to share engineering data in a collaborative design setting?" Second, the researcher structures the research area and develops suggestions for the design of the possible solutions based on his theoretical and practical knowledge. Third, the researcher and practitioners (potential end-users) together check the suggestions and refine them. Fourth, practitioners adopt and use the solutions. Finally, the results are reviewed in a joint process, in order to improve the solutions.

These efforts were done during an EC project EP 26780 SIMNET, between 1999 and 2002. The concepts were derived from a case study developed within two European companies (Rouibah & Caskey, 2005) and from existing theoretical knowledge on intercompany engineering collaboration. The proposed concepts were reviewed and refined in several workshops within the SIMNET consortium. The theoretical input from research, the practical input from SGP and Knorr, and the feedback from other members of the project lead to the improvement of the

concepts. The proposed enhancements were implemented as a prototype within the PDM axalant™ developed by Eigner & Partners.[1]

THE SIMNET METHOD AND PROTOTYPE

The proposed method, to be illustrated in the following section, is based on several concepts derived from a case study (Rouibah & Caskey, 2005). These are: parameters, parameter list, hardness grade, user categories, activities, parameter network, parameter approval and release workflow, engineering change management, and engineering change based on parameter propagations.

The SIMNET Method

The case study conducted within two European companies has shown that engineers' activities are unstructured. 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 and to affect relationships among parameters. Based on this finding, the Parameter Based Collaboration (PBC) was developed to structure the intercompany cooperation from the parameter perspective (Rouibah & Caskey, 2003a). PBC considers engineering activities as decisions about basic engineering attributes, termed here as parameters. The relationships between parameters and the people working with them capture the evolution of product design.

This approach describes complex product development as a form of parameter processing that involves roles and constraints. Each parameter has input and output parameters, which lead to us to consider engineering processes as a network of activities that uses and produces parameters (Figure 1). Evolution of parameters involves two kinds of workflows: administrative workflow (with predefined processes) and ad-hoc workflow (defined only prior to their execution). The parameter evolution is based upon the parameter approval and release workflow that constitutes the parameter life cycle (Figure 1). This process includes eight activities that were described by Rouibah and Caskey (2003a).

The PBC is also based on the concept of parameter maturity, noted *hardness grade*. This refers to the quality and stability of a parameter specification during design evolution. We used five hardness grades (noted HG) to upgrade parameters. Each parameter has to cross the eight activities and the five HGs during design progress. When a parameter reaches HG 5, it cannot be changed

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[1] Eigner & Partners does not exist anymore. Eigner was acquired by its competitor Agile Inc. (www.agile.com).

until a demand of change is initiated, studied, and approved. This is done by the Engineering Change Management (ECM) procedure (Rouibah & Caskey, 2003b). The ad-hoc workflow is based on the relationships we establish between parameters, product structure items (bill of material), and people who are assigned to these parameters (Figure 1).
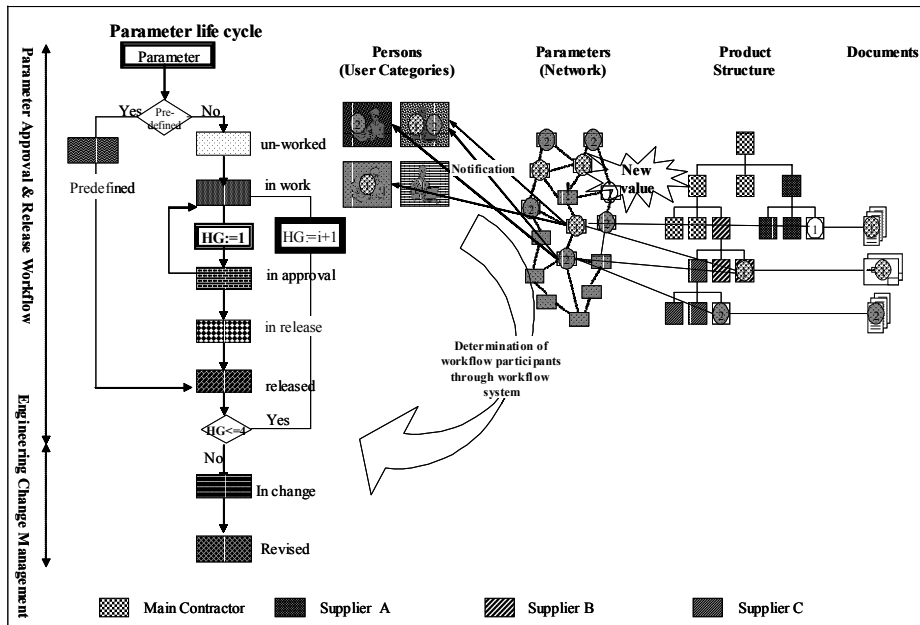

Figure 1. Framework of the PBC-supported engineering change

Source: Adapted from Rouibah and Caskey (2003b)

Working on parameters involves many engineers and other people, with different backgrounds, both from the main contractor and suppliers. Therefore, we specified five user categories to upgrade and work on parameters either inside the engineering area (coordinator, collaborators) as well as outside the engineering area (reviewers, subscribers, and supervisors). Their duties and privileges were also specified. Parameters may be presented to these roles individually or grouped as a list for possible upgrading.

Application of the PBC passes through several steps: instantiate a project container (i.e., a potential project for collaboration), define a set of parameters for collaboration independent from any project (i.e., parameters that are redundant in major projects); identify the five user categories within each partner and assign people to user categories; identify predefined parameters that are specified by the final customer (i.e., a customer who uses the final designed product); link parameters to product structure items; create values for the remaining parameters,

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apply the parameter approval and release workflow to upgrade parameters from HG1 to HG5.

The ECM approach is applied to move parameters within two other activities: "in change" and "revised" (see Figure 1). The ECM consists of propagating the change done on a specific parameter through parameter network when such as parameter is released and reaches HG 5. ECM evolves several steps: define interface parameter (i.e., parameters that are jointly defined by the partners); create the parameter network (i.e., a structure of parameter and their relationships); identify parameters requiring changes; propagate the change by auditing parameters directly and indirectly affected; discuss potential parameters affected by reporting the change to other users who may have interest; identify a list of parameters that effectively need changes; and apply a joint approval and release workflow for the parameter list.

Both PBC and ECM require a notification mechanism that is necessary to notify user categories about pending work in case of parameter change (approval and validation).

The SIMNET Implementation: The Distributed Workspace

In order to ease data sharing between the main contactor and its suppliers, we developed a distributed workspace prototype (Rouibah & Rouibah, in press). The workspace is used to publish parameters and associated objects (i.e., associated documents that support collaboration in a controlled manner). Nodes in the workspace represent a link to remote objects hosted at a partner's site. Nodes are built up on a project view on the desired product according to the partners' views. It eases handling of engineering data and avoids data duplication and data inconsistency. All project participants are able to access the workspace. The architecture is shown in Figure 2.

The distributed workspace enables online transactions and offline messages exchange. Online is the case when a native client program or a web browser interacts with the SIMNET application server. Offline is the case when the notification service may use standard e-mail to dispatch information to users of the engineering community (e.g., request an approval or/and validation of a specific parameter). The distributed workspace is managed by an Application Service Provider (ASP) which plays the role of a management entity and acts as a central gateway to access project relevant data.

Figure 2(a) illustrates collaboration between two companies, SGP and Knorr. They already published collaborative data (nodes) in the workspace. Nodes 1, 2, and 3 are under SGP, while nodes 4, 5, and 6 are under Knorr. Figure 2(b) shows

how a user from company "SGP" can request accessing data at company "Knorr" via the web client. First, he must log on to the workspace, managed by company "MC", in order to be recognized as a valid member of the engineering community. Second, if this is the case, he receives access to company Knorr. Third, he receives access to limited data hosted by Knorr (e.g., only to the authorized project). For such a purpose, the PDM system at Knorr checks if access is granted to this user. If so, data is checked out and presented in the web-client.
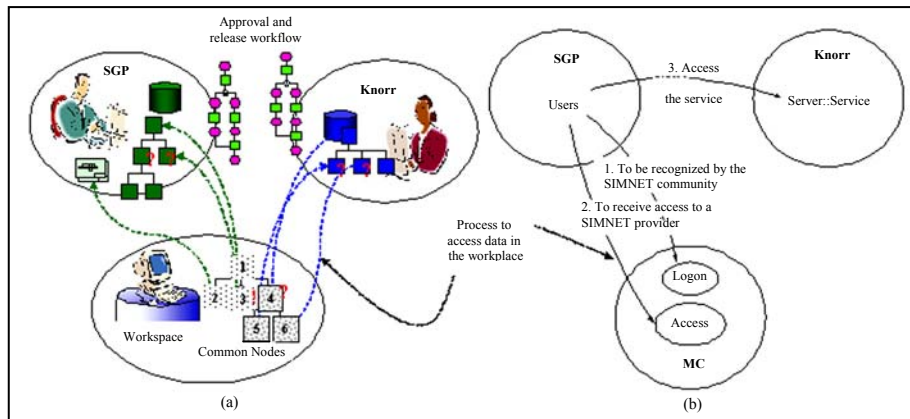

Figure 2(a) and (b). Architecture of the SIMNET distributed workspace

In addition, the workspace server is used to store the mapping between data coming from different source systems in the PDM system of the main contractor and the suppliers. Changes in one of the sites are communicated via the workspace notification, and users react accordingly. Applying the parameter approach enables engineers to track the ongoing product development during design progress. All requests for approval are directed to the *workspace in-box* of the user. The current view (state) of a parameter is presented by following the link provided in the work item. A list of allocated objects can be attached to this parameter and presented to users. To retrieve additional information, the user does not have to care where to get it from since this is handled by the workspace server. Requests are addressed to all servers that provide the needed information. Updates and modifications done by the user at a specific server (e.g., at SGP) are passed back to the workspace server.

Such a distributed workspace is based on the interconnections, through the Internet, of the partners (the main contractors and suppliers). All participants trust each other since strong security is deployed and ensured based on CLAVIS^{TM}, a full-strength security framework designed and developed by Mission Critical (www.miscrit.be). It plays the role of a management entity that is independent

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from any single organization and is trusted by all the members of the engineering community. The role of the management entity is to implement the security policies decided by the community and makes sure that the security is correctly enforced, while preserving the autonomy and visibility of the members. The management entity is also the certification authority. A strong security mechanism was deployed based on Public Key Infrastructure. All partners of the engineering community are peers (each organization plays the role of a client and a server at same time), except the management entity.

The main features of the prototype include several modules of the workspace:

- The parameter management module allows defining and managing several items associated with the PBC approach (e.g., parameters value creation, user name, and date of creation).

- The workflow module allows defining and executing administrative workflow as well as ad-hoc workflow when upgrading parameters.

- The workspace browser module enables people without a native axalant^{TM} client to participate in the parameter approval and release workflow.

- The notification service module is used to link the workspace axalant^{TM} with external e-mail systems.

- The security module is used to authenticate users of the workspace and secure data exchange.

TESTS

The test of the method and the prototype took place in a pilot phase (Schmitt & Fortmüller, 2001). The test introduced the method (and its underlying concept) and the prototype to a limited area of SGP and Knorr. Four test phases were used:

1. creation and management of user categories and a parameter list without a notification service for three months;

2. management of the parameter list with notification service takes place after the previous, and lasts for one month;

3. management of the parameter list with approval and release workflow starts after the previous lasts for two months; and

4. management of parameter networks including change management and notification start after previous phase and lasts for two months.

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Product and Participants in the Pilot Phase

In order to test the SIMNET solutions under real project conditions, a development project that integrates the magnetic track brake into a specific railway bogie platform (the SF 3000) was chosen. The test involved two European companies (SGP and Knorr). SGP manufactures the bogie frames and engine, while Knorr manufactures the magnetic track brake. The magnetic track brake operates independently from the friction between wheel and rail. It is installed in the bogie frame.

Twelve people from SGP and two from Knorr were involved in the pilot phase. SGP was represented in the test by five people at the strategic level, two from the tactical and five from the operational level. Knorr was represented by one person from the operational and the strategic level, and a second from the operational level. People in the operational level refer to those directly involved in testing the pilot application. People in the tactical level refer to those who are responsible for organizational matters (e.g., the appointment of meetings, setting of due dates). People in the strategic level refer to those persons responsible for strategic aspects and decision-making as well as the enhancements of the method/prototype. In addition, a test evolved other people from other companies, including a senior consultant from an information and communication technology (ICT) company, a project manager from Eigner & Partners that develops the PDM axalant[TM], and the CEO of Mission Critical, an IT security company.

Data Collection

Problems encountered during the pilot phase were reported to the corresponding supplying partner (Eigner & Partners, and Mission Critical) based on screenshots and additional comments. Due to the nature of the solution and its importance for the pilot phase most reports referred to the parameter management and the parameter-based approval and release workflow. Problems identified or reported were solved quickly. During the test, participants were asked to evaluate both the SIMNET method and the prototype. Two methods of data collections were used: survey questionnaire to collect quantitative method, and a semi-structured interview to collect qualitative data.

The *portfolio method* developed by Professor Horst Wildemann was used for the test purposes. The portfolio method is shown in Figure 3(a). It is based upon two criteria: *importance* of the concept to the customer and the level of *fulfillment*. We have selected this method because it serves to identify the need for improvement in a company through evaluation of its benefits. Such benefits could be identified in terms of:

1. immediate actions through a complete redesign of existing practices;
2. immediate improvements of existing practices;
3. step-by-step improvements of existing practices;
4. no need for actions; and
5. a potential for rationalization.

The Wildemann's portfolio method has been customized to successively evaluate the *method* (Figure 3[b]), the *implementation* (Figure 3[c]), and also to orient to the *potential improvement of both the method and the implementation* (Figure 3[d]).
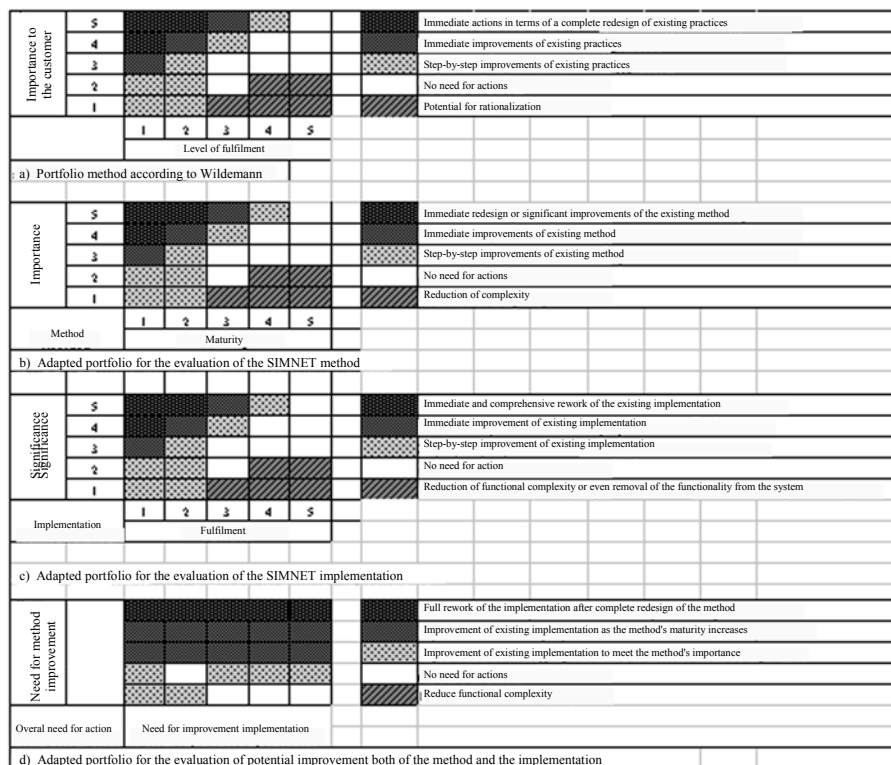

Figure 3. Portfolio method and its customization for the evaluation of SIMNET concept and prototype

The customized portfolio of the method is based on the *importance* and *maturity* (Figure 3[b]). Importance refers to how participants perceive the method as important to their activities. Maturity refers to how participants perceive the method as mature (achieve expected benefits) and does not need extra improvements. The customized portfolio for implementation is based on the *significance* and *fulfillment* of their implementation (Figure 3[c]). Significance

refers to how participants perceive the implementation as stable, quality-based, and user friendly. Fulfillment refers to how participants perceive the achievement during the implementation compared to their manual tasks. The customized portfolio for potential improvement is based on the *method achievement* as well *implementation fulfillment* in relation with the need to increase the maturity of the SIMNET methods (Figure 3[d]).

The SIMNET method including the nine concept solutions (see first row in Figure 4), was evaluated against their expected benefits. The nine concept solutions are:

1. the centralized management (the workspace), accessibility and visibility of the system and interface parameters for engineering staff through the axalant™ native client (by people in the engineering field);

2. the accessibility and visibility of the system, and interface parameters for people outside engineering through the axalant™ web client;

3. the automated notification service for people in- and outside engineering;

4. the hardness grade concept;

5. the user category concept;

6. the parameter-based approval and release workflow for people inside engineering through the axalant™ native client;

7. the parameter-based approval and release workflow for people outside engineering through the axalant™ web client;

8. the concept of parameter networks based on sets for the traceability of change propagations; and

9. the method for parameter-based change management.

Each of these nine concept solutions is evaluated against the quantitative and qualitative benefits (see first column of Figure 4). To evaluate the SIMNET method, participants need to create two matrices (Figure 4): one matrix for potential achievement of benefits (represented by "P" in Figure 4) and a second matrix which refers to the level of achievement (represented by "V" in Figure 4). However, for simplicity, the two matrices were merged into one. Accordingly, the evaluation of each concept solution requires two values (P and V), which enable us to generate the portfolio method "potential vs. achievement".

Figure 4. Results of the evaluation

To evaluate the SIMNET implementation, participants also need to create two matrices (see Figure 4): one for significance (represented by "S" in Figure 4), and another for the level of fulfillment (represented by "V" in Figure 4). These two variables enable to generate the portfolios implementation "significance vs. fulfillment". The portfolios for follow-up actions are based on the *method fulfillment* and *implementation achievement*.

Test Results

Analysis of questionnaires shows the following results. The initial concept of composing parameter networks turned out to be too rigid. It was, therefore, replaced by a more flexible approach, which allows the creation of user-specific parameter sets. Scenarios with the parameter-based change management functionality revealed a need for significant changes of the underlying procedures and methods. With respect to quantitative benefits in terms of reduced engineering hours and avoided costs, concepts of SIMNET were evaluated by the end-users to be very helpful, especially as far as the "clarification of the current state of work", "elaboration of corrective measures", and "change costs" were concerned. The qualitative benefits were seen in "support of quality assurance" and "improved evidence in case of disputes". Substantial conceptual changes were required regarding the manner in which the parameter networks are defined (introduction of "parameter sets") as well as how the parameter-based change management was performed. The parameter-based change functionality was under continuous modifications and refinements until the very end of the pilot phase and the SIMNET runtime. In addition, the feedbacks obtained on parameter networks and change management are considered extremely useful to achieve a higher maturity of the entire SIMNET concepts. With regard to the perceived usefulness of SIMNET implementation, results show the following. The quality of implementation in general resulted in high rankings. Exceptions are the parameter-based change management functionality, which receives low ranking, the functionality based on the web client is ranked medium and the functionality for the definition and management of parameter networks via sets is also ranked medium.

Interviews highlight additional findings. Participants did limit their reactions only to five concept solutions, among the nine, either positively or negatively. As for the first concept solution, i.e. the centralized management, participants believe *project container approach is easy to handle*. They propose that *parameter attributes defined at definition level should be selectable for instantiation from a menu*. Participants believe the *existence of the parameter definitions independent from a specific project is very useful and can be used like templates to facilitate initiating a new project*. As for the hardness grade concept, all participants *agree to consider the five grades as convenient to control design progress and its*

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quality. As for the user categories concepts, participants believe the *subscriber is useless since he may become a nuisance*. For the concept of parameter network based on sets for the traceability of change propagation, participants think that *it is really hard and often difficult to distinguish between first degree relation and n^{th} degree relation*. As for the method for parameter-based change management, participants think the *parameter change management procedure is too simplified compared to the real life use in bogie design*. Moreover, they found the *parameter change procedure is facing problems especially if parameters candidate to change appear on more than one change list*. In addition, two participants believe user interface of the change management functionality based on the web-client is good but unstable.

Other quotations were made against the proposed SIMNET method. All participants agreed *collaboration engineering is important and promising for senior managers and where savings may be generated*. Other participants also state that the PBC approach is a *a way to structure collaboration and coordination among a community of partners*. Another added *this approach is helpful to better communication during collaboration engineering*. Another added *the PBC allows dynamic data sharing in a controlled manner but it needs further improvement*.

CONCLUSION

This paper highlights the experience of an European engineering project in order to further knowledge about collaboration engineering. The overall conclusion of the pilot phase is that collaboration engineering is potentially important for senior managers. End-users were specifically attracted more by the concept itself rather than by the implementation. They consider the SIMNET results (method and prototype) very useful and of high quality. Except from the parameter-based change management, the functionality could be sufficiently tested. Accordingly, the pilot phase itself can be evaluated as satisfactory for user categories, parameter lists without notification, parameter lists with notification, and approval and release workflow, but the pilot phase can be evaluated as unsatisfactory for parameter network and change management, while very useful feedback was obtained for the further development of the entire solution for parameter-based workflow management. These results reveal that intercompany engineering change management is a very complex process.

Besides the above findings, the SIMNET method and its implementation faced unexpected circumstances. The workspace implementation has suffered from a major setback by Siemens (a major stakeholder in SGP) rejecting axalant™ as their PDM solution in favor of Windchill (www.ptc.com). The new Siemens'

Board of Directors of transportation systems decided not to further implement axalant™ and to adopt the PDM Windchill.

Besides this drawback, the workspace solution, the core of this paper, proposes significant improvements to Siemens SGP processes with a potential for these improvements to be incorporated in its Windchill platform. The adverse decision of Siemens with regard to axalant™ demonstrates the fragility of one-to-one (SGP-Eigner & Partners) developments when it comes to cross-enterprise collaboration. Interoperability between heterogeneous PDM and workflow systems cannot be handled without careful assessment of political ramifications. This suggests several observations. First, technical competencies of Eigner & Partners are not a sufficient condition for strategic information system development's success. Second, development of interorganizational information systems is very complex to approach. The workspace's functionalities were under continuous modifications and refinements until the very end of the pilot phase. Accordingly, the research action must be approached carefully if the research involves several companies. Third, rather than IT competencies, it is the support of strategic management level (at SGP) that constitutes the critical success factor for the achievement especially for system that cross company borders (Lederer & Sethi, 1991). Fourth, the European Community sponsors projects that are of high quality and high innovativeness within a period that ranges from one to three years. For such projects, it spends huge investment (the SIMNET project was sponsored around €2.2 millions). Even though a lot experience has been acquired, the results were wasted. Beside the Siemens decision, other factors have led to a willingness to pursue the workspace implementation by Eigner & Partners. With the emerging market of workspace, Eigner was acquired by its competitor, Agile (www.agile.com), leaving the Partner alone. This unexpected event pushed Partner to abandon the workspace and to refocus its entire business around the Enterprise Application Integration and to incorporate some of the workspace functionalities on its PDM system. Finally, this paper leaves the following research question as perspective: Does the approach (concept/prototype) improve user ability to perform design tasks and whether a product design (result/development) becomes better?

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