Integration of business processes in Web-based collaborative product development

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Abstract

Collaborative product development is a growing trend as companies seek worldwide opportunities to extend their market as well as small and medium sized engineering enterprises concentrate on their core competences. Internet and Web technology facilitates the information sharing and exchange among widely distributed collaboration partners, however, the integration of business processes with the support of Web-based applications is the final goal because business processes represent the knowledge of how to reach the collaboration goals. The research results presented in this paper concern business process integration developed as part of the Europe-China project called DRAGON, which aims to develop an Engineering Portal to support collaborative product development. The reference business processes are extracted from the questionnaires completed by specially selected collaboration companies from Europe and China. The constraints, the needed functionalities of the engineering portal, of the whole collaborative product development process are analysed with IDEF0. The emphases in business process integration are put on the application of concurrent engineering principle and workflow management technology. Information integration is ensured by sharing a STEP-based product model and mapping STEP model to XML data. The solution for the coordination problem of a product development team is based on workflow management technology.

1. Introduction

Complex products are often developed as a result of collaboration between many partners, each of which possesses expertise related to a specific industrial sector. Therefore, collaborative product development has become a strategic issue to develop high quality products at low cost and with quick response times to market demand. Nowadays, collaborative product development is further promoted by the growing trend towards a world market. There are strong needs to manufacture a product in the country where it is to be sold, in order to react more quickly to the customer demands in the local market (Grabowski and Lossack *et. al.* 2002). Collaboration between globally distributed partners with different cultural backgrounds is inevitable. Finding suitable partners in a foreign market and establishing collaboration with them is often very time-consuming and expensive.

Once the collaboration relationship is established, information for performing engineering tasks has to be exchanged across the organization boundary between the collaboration partners. The coordination of partners with different cultural backgrounds requires more efforts in the collaboration engineering process due to the different approaches for solving technical problems. These factors make the management of the collaborative product development process quite difficult.

Utilizing the rapidly developing Internet and Web-technology, it is possible to build a virtual marketplace for enterprises to select partners and to establish a collaboration with them (Ho and Fung *et al*. 2000, Lau and Wong *et al*. 2001). It is also possible to develop a platform for supporting the collaboration engineering processes among partners (Huang and Mak 2001, Nidamarthi and Allen *et al*. 2001, and Cheng and Pan *et al*. 2001). The Europe-China project DRAGON (IST-2000-29366, Development of an inteRActive enGineering portal for Open Networks) aims to develop an engineering portal to innovatively support

collaboration between business partners not only from Europe and China, but also from countries worldwide (Grabowski and Lossack *et. al.* 2001). The distinguishing feature of the DRAGON engineering portal is that it supports the whole collaboration process, including searching for potential partners, evaluating and selecting partners, and collaboratively developing products.

One of the challenges in developing such an engineering portal is how to streamline the business processes of the participating partners. In this paper, the integration of the business processes for collaborative product development is reported, which is one of the milestone results of the DRAGON project. In section 2, the process modelling technologies from available literature is reviewed from the perspectives of information system engineering. Because the IDEF0 method provides a means for capturing the characteristics of problems at the requirements modelling level and for identifying the functions required by a system, it is used in section 3 as the approach to model the business processes supported by the DRAGON engineering portal. The principle of concurrent engineering is applied by sharing a STEP-based product model to keep the solutions of different engineers consistent within product development process. The mapping STEP model to XML data and the SOAP-based communication are highlighted in section 4 as the foundations for business process integration. The DRAGON engineering portal as the integration platform and the application of workflow management technology to business process integration are described in section 5. Finally, concluding remarks are given in the last section.

2. The prerequisites of business process integration

2.1 *Business process*

A business process is a sequence (or partially ordered set) of enterprise activities, execution of which is triggered by some event and will result in some observable or quantifiable end result (Vernadat 1996). The process model of a business process is an abstract description

of the business process being modelled. Process modelling is the prerequisites for business process integration because it helps to understand how the business processes work and formalises the business processes to be integrated.

2.2 *Existing approaches for process modelling*

The purpose of modelling business processes is to represent, plan, communicate, analyse, synthesize, re-engineer, integrate, or execute them. Existing approaches for process modelling include IDEF0, IDEF3, Data Flow Diagram (DFD), Integrated Enterprise Modelling (IEM), Unified Modelling Language (UML), and workflow modelling etc. From the methodology point of view, these methods can be categorised as functionally oriented (IDEF0, DFD), object-oriented (IEM, UML) or process-oriented (IDEF3, workflow modelling). From the perspective of information system engineering, some of these process modelling methods are used to create descriptive models for capturing requirements and analysing systems (IDEF0), for planning and optimising the processes (IDEF3, IEM) in the business-oriented phase, or for creating implementation models in the system design phase (DFD, UML and workflow modelling). UML is a modelling language for specifying, visualizing, constructing, and documenting the artefacts of system-intensive processes (Alhir 1998).

Workflow management is an implementation strategy for cooperative information systems (Jablonski and Bussler 1996). In order to apply workflow management technology, the business process should be modelled as workflows with workflow modelling technology first. Workflow modelling technology aims to integrate functions, data, applications, people, organization structures, etc. It offers a systematic approach to turn islands of automation into a value chain. The modelling elements provided by different build-time tools are different. For example, the process definitions defined with SAP R/3 (Trade mark of the German company SAP AG) workflow modelling tool are different

from that defined with iMAN (Trade mark of the US company EDS) workflow modelling tool. Therefore, it is required in practice that a process definition generated by one modelling tool can be executed by a number of different workflow run-time products. The workflow Management Coalition proposes the Process Definition Interchange Specification (WFMC-TC-1025) for transferring vendor specific workflow models.

2.3. *The process modelling approaches of DRAGON*

The business goals, and the business domains that the DRAGON engineering portal pertains to are obtained through the questionnaires in the business planning phase. Five specially selected companies are interviewed. Their business collaboration forms cover a European-Chinese joint venture, a large European company, which have created engineering collaborations with many Chinese enterprises, a large Chinese company and a medium-sized traditional Chinese company. The questionnaires are completed by each of the interviewed companies. In the business analysis phase, the As-Is collaborations are analysed and the To-Be business processes are built up with IDEF0. In the system design and system implementation phases, the precedence of the activities in the *Search Partner process* and the *Establish Collaboration process* are embedded in the corresponding business services modules, as the business logic of these business processes is comparatively simple. On the other hand the *Develop Product process* are modelled as workflows with the workflow modelling tool of developed by one project partner. The process definitions generated with the workflow modelling tools can be exported in XML format that can be easily shared and exchanged between the collaboration partners.

3. System analysis

IDEF0 provides a means for modelling the functions (activities, actions, processes, operations) required by a system or enterprise, and the functional relationships and data that support the integration of those functions (Dorador and Young 2000). Therefore, it is

used to model the business processes that are performed by the collaboration partners.

[Insert figure 1 about here]

The A0 diagram is shown in figure 1, which illustrates the context of collaborative product development supported by the DRAGON Engineering Portal. Apart from the organization boundaries and the geographical locations of the collaboration partners, collaborative product development is also constrained by the different engineering data format used and the heterogeneous application systems involved. The Web-based DRAGON engineering portal is used to break these constraints and to support the communication and coordination between collaboration partners

The collaborative product development process described by the A0 diagram is decomposed into three major steps: search partners, establish collaboration, and develop product, as shown in figure 2.

[Insert figure 2 about here]

3.1. *The Search Partner process*

In the *Search Partner process,* the engineering portal serves as an electronic marketplace for OEMs to initiate contact with potential suppliers or joint venture partners coming from a particular industrial sector. The input of this process is the profile of the collaboration partner required by OEM, while the output is the pre-selected partners that fit the profile. The pre-selection of the partners needs the engineering portal to match the requests of OEM with the registered information about product/service and to evaluate the matching results.

3.1.1. *Challenges and solutions*. In the *Search Partner process,* the enterprise that intends to provide products or services should publish their offers first. Then the profile of the collaboration partner required by the OEM is matched with the published information to generate the list of potential partners. For publishing information, Internet and Web technologies today allow nearly all types of information, such as sound, text, pictures, animations and videos concerning an enterprise, to be published. However, if

the information is not qualified or organized into a formal structure, they will not be processed effectively for decision-making. Therefore, the registered information on product and service should be elaborately selected. The aim is to control the amount of the information to be published, thus to avoid the occurrences of the following cases:

- Information overload or redundancy
- Lack of information about the product or service provider

In the former case, the efficiency of matching the profile of the required collaboration partner with products or services information will be severely reduced (Ho and Fung *et al*. 2000). In the later case, the product or service provider will not be wholly evaluated. Therefore, the problems within the *Search Partner* process are:

- What information about an enterprise as well as its products and/or services should be published?
- What measures should be taken if there is lack of information in the matching process?

The solution of the DRAGON engineering portal is to explicitly express the knowledge required for contact initiation. A pre-defined attributes set, called *Attributes of potential partner*, is provided. Attributes of potential partners represent the initial requirements of OEMs. Therefore, they are referred to by OEMs to define the searching conditions. Because product/service providers publish the information that is of concern to OEMs, products and services providers also refer to the attributes of potential partner when they register their offers in the DRAGON Portal. Apart from the basic information such as the name, location, contacts etc., the attributes of potential partner include the following information:

- The Standard International Trade Classification (SITC) or International Standard Industrial Classification (ISIC)
- The relevant certification situations such as ISO 900x etc.
- The quality assurance measures such as measuring equipments, sampling methods, and quality control methods

3.1.2. *Required services and the involved components of the portal*. The *Search Partner* process needs the following portal services: the *Product/Service Registration* service, the *Search for Potential Partner* service, the *Matching* service, and the *Evaluation of Matching Results* service.

A product or service provider accesses the *Product/Service Registration* service, which further accesses a library of pre-defined attributes. The product/service provider can select the information that they wish to have published. Attributes not in the library may be defined by the product/service provider and added to the appropriate library category. Through the navigation of the *Product/Service Registration* service, the entire set of attributes for potential partners are accessed and the offer information about the product/service provider is registered in the Product/Service Database of the portal.

Similarly, an OEM applies the *Search for Potential Partners* service, which also accesses the pre-defined attributes library. The OEM can define the requirements information through the navigation of the *Search for Potential Partners* service. The initial requirements for the potential partners are submitted to the DRAGON engineering portal. The submitted requests are matched against the registered offers from the products/services providers. The matching results are a list of potential partners. The OEM then makes a pre-selection from the list of potential partners for further detailed evaluation based on a weighting factor for each requirement attribute.

Since the *Product/Service Registration* service and the *Search for Potential Partners* service access the same library of attributes, the offers and the OEM's request can be matched effectively. Moreover, missing information, which the product/service provider may choose not to publish, will be easily detected. In such cases, a Request for Information (RFI) e-mail will be automatically sent to the product/service provider, leading to an update of the potential partners profile based on the requested

information (Grabowski and Lossack *et al* 2001).

It is possible that some of the products/services provider will choose not to submit the missing information. In such cases, the matching processes should not be suspended indefinitely. Specifying a deadline for answering the requests is necessary. When the deadline is reached, the evaluation process for the partners not providing the missing information continues.

The result of the *Search Partner* process is a list of potential partners. The *Search for Potential Partners* service also deals with the cases of too long or too short a list of potential partners. For example, if the list is too short, some specific requirements in the original request might be removed, while if it is too long, more specific attribute requirements could be added to the original request and the matching service run again

The objective of the *Evaluation of Matching Results* service is to support OEMs to evaluate and to rank the potential partners generated in the *Search Partner* process. Each attribute to be evaluated is assigned a weighting factor representing its significance in collaboration. The extent to which an offer attribute of a potential partner matches the request attribute of an OEM is calculated. The total score of a potential partner is the weighted sum of all the scores gained in the evaluated attributes. The outcome of the Evaluation of Matching Results service is a ranked list of potential partners. Then the OEMs can pre-select some partners among the ranked list of potential partners and start to negotiate with them. The IDEF0 description of the *Search Partner* process is shown in figure 3.

[Insert figure 3 about here]

3.2. *The Establish Collaboration process*.

In the *Establish Collaboration* process, the pre-selected potential partners are evaluated in terms of attributes for future engineering collaboration, such as the competence of a potential partner in its specific industrial sector, the computer-aided application systems used (e.g. CAD, CAM or PDM), the supported engineering data format, and the

means of information sharing and exchange provided. For example, if the potential partner is a dies provider, its abilities to produce dies with desired rigidity, tolerances and specified surface finishes as well as to perform mechanical analysis such as the deformation and strain of the die under high temperature etc are checked. After investigating the engineering collaboration aspects of the pre-selected potential partners, the potential partners are further qualified. The OEM negotiates with each of the qualified potential partners on the delivery aspect of the products and services such as the cost and delivery time. Finally, the OEM selects the most suitable partner for each industrial sector and establishes a formal collaboration relationship with it.

3.2.1. *Challenges and solutions*. The *Search Partner* process is the same for suppliers and joint venture partners. However, the *Establish Collaboration* processes of OEM-supplier relationship and joint venture are very different in the risks that are taken by the partners, in the intensity of the interrelations of the partners, and in the purposes of the partnership (Grabowski and Lossack *et. al.* 2002).

It can be seen that the OEM needs the knowledge to evaluate the engineering collaborations with partners from various industrial sectors. The OEM also needs the support for the establishment of different collaboration forms.

The solution of the DRAGON engineering portal is to explicitly express the knowledge needed for evaluating the potential partner from a certain industrial sector. A pre-defined attributes set, called the attributes of the collaboration partner, is provided. Attributes of the collaboration partners are dependent on industrial sectors and represent the information about collaboration aspects that should be investigated when evaluating the potential partners for the final selection. For example, potential partners from mechanical engineering should be investigated based on the computer-aided application systems used (e.g. CAD, CAM or PDM), the engineering data format supported, the support of STEP

(STandard for the Exchange of Product model data) and the relevant application protocol, and the communication media etc. Attributes of collaboration partners are organized according to the SITC classification or ISIC classification.

For the establishment of OEM-supplier relationships, the requirements of the OEM and the offers of each pre-selected partner are merged and displayed in certain Web pages, which serves as the basis for the negotiation. For each merged attribute, there will be two fields, one corresponds to the offer of the supplier; the other corresponds to the requirement of the OEM. The OEM and each pre-selected suppliers will carry out a number of negotiations. During each loop of negotiation, the OEM can further refine its requirements by adding new attributes and their weights to the original ones. Each pre-selected partners may choose to reply to the newly added or adjusted existing attributes. Negotiation itself is carried out off-line due to its complexity. But the results of each negotiation loop are applied to a comparison algorithm through the weighted offer and request attributes for evaluation of how closely matched both parties are. The number of negotiation loops depends on the complexity of the supplied part or component. Finally, the OEM selects a partner and issues a Request for Proposal (RFP) to them. If the supplier accepts the RFP and makes a proposal, a contract is signed and the OEM-supplier collaboration is established.

The establishment of joint venture collaboration is more complex because of the foundation of a third legal party. The engineering portal only supports the OEM to issue a questionnaire to the potential joint venture partner. The negotiations are conducted outside the scope of the portal.

3.2.2. *Required services and the involved components of the portal*. The establishment of OEM-supplier collaboration is supported with the *Evaluation of Negotiation* service. The establishment of OEM-supplier collaboration needs to access the product/service database, the pre-defined attributes of collaboration partners and to use

the template of the Request for Proposal provided by the portal. The attributes of collaboration partner are combined with the attributes of potential partners, forming the Attributes Library of the DRAGON engineering portal.

For the establishment of joint ventures, the DRAGON engineering portal only provides the OEM with a questionnaire template, which will be issued to its pre-selected joint venture partners. The IDEF0 description of the Establish Collaboration process is illustrated in figure 4.

[Insert figure 4 about here]

3.3. *The Develop Product process.*

In the *Develop Product* process, the market demand or customer requirements are transformed into product specifications and manufacturing specifications. The collaborative product development needs the support of engineering applications such as CAD and PDM systems. However, the heterogeneity of these applications and the used data format constrain the information sharing and exchange. Therefore, the collaborative product development needs the DRAGON engineering portal to support information exchange and product development coordination.

3.3.1. *Challenges and solutions*. A Product development process usually lasts several weeks, several months, or even several years. Product development is also an innovative process since the intelligence of the engineers is necessary. As the product development process undergoes the requirements modelling, conceptual design, preliminary design and detailed design phases to meet the increasingly complex product specifications, information is frequently exchanged. Engineering changes frequently occur in the product development process for continuous improvement and determine as much as 70% to 80% of the final cost of the product (Chen and Shir *et al* 2002). The main challenge in the product development process is to keep the solutions of different engineers consistent within the life cycle of the product, so as to minimise engineering change activities and to

speed up the development process. Another challenge is the sharing and exchange of information between collaboration partners.

The solution for the communication problem within the Develop Product process is concurrent engineering. Concurrent engineering concerns the integration of complementary engineering expertises, communication of upstream and downstream product life-cycle development activities, and the coordination of problem-solving teams in order to reduce the cost and the time-to-market of new products for better customer satisfaction (Vernadat 1996). The solution for the communication problem between engineering activities of product life cycle is based on sharing a common product model. The international standard for the expression and exchange of product data is STEP. STEP uses the EXPRESS language to describe product model in a neutral and consistent data exchange format. Therefore, the involved applications of the collaboration partners should support STEP and a common product model should be defined.

The solution for the coordination problem of a product development team is based on workflow management technology. A workflow model defines the objects in a business process, such as activities (representing a process step or a work item to be accomplished), process participants, the invoked applications and the relevant data objects for the execution of the business process. A workflow model also defines the attributes of the objects in a business process and the relationships between these objects, such as the transition between the activities and the logical relationships between these transitions (AND, OR, XOR etc.). For the purpose of synchronising parallel engineering activities, milestones can be defined in the workflow model according to a product development plan. At each milestone, the development results of each collaboration partner are merged into one harmonized result, which is achieved by comparing the newly created solutions with the previous solutions, and compromising the conflicting solutions.

3.3.2. *Required services and the involved components of the portal* The Develop Product process needs the following services of the DRAGON engineering portal: the *Information Sharing and Exchange* service, the *Process Modelling* service, and the *Workflow Execution* service. The information sharing and exchange service is discussed separately in section 4 as the foundations of business process integration.

The *Process Modelling* service is used to plan the execution of business processes, produce the workflow model that can be instantiated and executed by the workflow engine. The process modelling service provides a visualised user interface as well as sufficient and straightforward modelling elements for planning and defining the workflow model of business processes.

The *Workflow Execution* service is implemented as one or a group of cooperative workflow engines. Workflow engines are application servers which communicate and cooperate with each other to the execute tasks such as accessing the workflow process definition of the business process to be executed from the process model repository, creating the respective process instances, assigning the task of manual activities to the work-list of the proper actors or notifying the actors, and controlling the execution of all the previously created process instances.

A basic approach of workflow management is that the workflow information is pushed from one actor to the next (Riempp 1998). Under the control and navigation of workflow engine, tasks are *pushed* from one process step to the next according to the process definition. Therefore, the workflow management system is an active system. However, for a Web-based application such as the engineering portal, the underlying information sharing technology is pull-oriented, i.e. it is impossible to push a web page to a specific recipient (Riempp 1998). In order to implement the *push* functionality of workflow management in the engineering portal, two strategies can be adopted:

- Provide active client of workflow execution service to the engineering portal
- Combine web-browser with email client

The finished workflow model of a business process is stored in the *Workflow Model Repository* and released for initiation and execution by the Workflow Execution service. The instantiated workflow instances are stored in the workflow instance repository. The IDEF0 description of the Develop Product process is shown in figure 5.

[Insert figure 5 about here]

4. The foundations of business process integration

Integration means bringing together heterogeneous components to form a synergistic whole. In the context of the Web-based collaborative product development, the business process integration falls into the category of inter-enterprise integration, i.e. integration of business processes of a given enterprise with business processes of other enterprises, or even sharing some parts of business processes by different cooperative enterprises. Therefore, the integration of business processes is high-level integration, which is based on information integration and application integration (Vernadat 1996). Information integration is realised through information sharing and exchange, while application integration is realised through interoperability.

4.1. *Information sharing and exchange*

4.1.1. *The representation of data with XML*. In order to exchange information across organization borders with the support of the engineering portal, the collaboration partner should use an open and easily implemented Web standard for information exchange. A potential standard for exchanging various types of information between heterogeneous systems using Web technology is XML (Extensible Markup Language).

4.1.2. *XML-based data modelling*. As the data to be exchanged in Web-environments are represented with XML, the corresponding data model should be built up with an XML schema or a Document Type Definition

(DTD). Because an OEM plays the role of integrating the development results of its collaboration partners into a whole product, while the collaboration partners come from various industrial sectors, the common data model shared by the OEM and one of its partner should be industrial sector dependent, which defines the information that will be shared and exchanged in that specific industrial sector.

In order to support the collaboration partners to determine the information to be shared, the engineering portal provides the XML schemas or DTDs as the common data model of most industrial sectors. When creating the XML documents, the engineers can select the necessary elements or attributes and add additional elements or attributes.

4.1.3. *Mapping between the XML document and the STEP file.* STEP is widely used as the international standard for the exchange of product model data. The utilisation of STEP realises the sharing of the information during the product life cycle and concurrent engineering, which shortens the product development period. However, the application system cannot exchange the product data defined with EXPRESS language directly through the Web. Therefore, there is a great need to combine the advantages of the two languages. The standard for representing EXPRESS models and data with XML is ISO 10303-28, named XML Representation Methods for EXPRESS-Driven Data. For the applications to exchange data with the support of the engineering portal, there must be a mapping from STEP model to XML data and vice versa.

4.2. *SOAP-based information exchange*

The engineering portal plays the role of information exchange centre for collaboration partners. After the product data from the involved application systems are mapped to XML, they can be exchanged using Web-based communication protocol. SOAP (Simple Object Access Protocol) is the protocol that serves this purpose. XML data is embedded in SOAP messages and transferred through HTTP protocol.

Therefore, SOAP is an open and platform independent application communication protocol that can be easily adopted by enterprises to implement information exchange in the Web environment.

5. **The implementation of business process integration**

5.1. *The architecture of the engineering portal*

The DRAGON Engineering Portal is a typical Web-based application with a three-tier architecture. The first tier includes the application clients, which are usually standard Web browsers. The middle tier includes Web-servers and application servers. The Web server processes the HTTP requests from the application clients, and returns the Web pages for presentation. The application server performs computations according to business logic, returning the results to the Web server. The third tier provides data services for the Web servers and application servers. The components that provided the business services are located in the middle tier of the engineering portal as application servers.

5.2. *Business process integration*

The integration of the *Search Partner* process and the *Establish Collaboration* process is based on sharing the common attributes library, and the support of the underlying business services. For example, the completion of the *Search for Potential Partner* service automatically triggers the *Matching* service, while the completion of the *Matching* service automatically generate Request for Information.

The integration of the Establish Collaboration process and the Develop Product process is based on the common data objects that are created after the establishment of collaboration, such as the name of the project, the document folder, the project and its location in the DRAGON engineering portal, the name of the collaboration partner as well as its representatives and contacts etc. The process modelling service should be able to access these data objects when creating the workflow model of collaborative product

development process, and so should be the workflow execution service when executing the workflows.

In the *Develop Product* process, the internal engineering process of the OEM and its collaboration partners should be integrated. The integration is based on sharing a STEP-based product model pertaining to the respective industrial sector, and mapping STEP model to XML data. The organization integration of the product development team, and the application of workflow management technology are also the important aspects of the integration of the engineering process of collaboration partners

5.3. *The organizational integration of the product development team*

When coordinating the product development process with workflow management technology, not only the activities, and the logical dependencies between these activities should be modelled, but also the workflow participants and the policies to assign the tasks should be defined in the process model as well. If the tasks are directly assigned to the users, or the organization model is defined within the workflow model, the process model will lack flexibility as the workflow process should be re-defined when the organization structure or the members of the project team of each collaboration partner are changed.

In order to enhance the run-time flexibility of workflow management functionality, the organizational model of the product development team is separately defined, which will be referred to by the relevant workflow model, as shown in figure 6.

[Insert figure 6 about here]

The organization model for collaborative product development defines the objects, their attributes and relationships concerning the collaborative product development team. The main objects of the organization model are the OEM team, partner team, department, workgroup, user and role etc. The relationships between organization objects include ‘Play Role’, ‘Belong To’ and ‘Supervise’ etc. Both the objects and their relationships have attributes.

5.4. *The workflow model of the collaborative product development process*

In collaborative product development, the collaboration partners need only to know the requirements of the product part defined by the OEM, and submit the development results. It is required that the internal product development processes representing the technical know-how of the collaboration partners should not be exposed. Moreover, the product development process is highly dynamic and it is difficult to model its details in advance. Under these modelling requirements, the workflow model supported by the DRAGON engineering portal describes only the major steps in the collaborative product development, as shown in figure 7.

[Insert figure 7 about here]

Firstly, the OEM defines the initial product structure. Then two activities happen in parallel: the OEM exports the initial product structure to the portal and makes the relevant product structure available for the respective collaboration partners; The portal notifies the collaboration partners of the event. Milestones are defined in this activity according to the product development plan. When a milestone is reached, two activities happen in parallel: each collaboration partner is reminded to export the milestone development results to the portal. The portal notifies the OEM of the event. The OEM imports the milestone development results to its local application system, and decides if an engineering change is necessary by checking the milestone development results of all collaboration partners. If the engineering change is necessary, the engineering change sub-process is invoked. The check activity and engineering change sub-process are looped until the engineering change is unnecessary. Then the process determines the project status as ongoing or end.

The engineering change sub-process starts with the OEM marking the original solutions that do not satisfy its requirements. Then the Engineering Change Order (ECO) is created. The next two activities happen in parallel: the OEM exports the marked solutions as well as

the engineering change proposals to the portal; the portal issues the ECO to the involved collaboration partner. On receiving the ECO, the collaboration partner imports the marked solutions to its local application systems and finds new solutions. The new solutions are exported to the portal and the engineering portal automatically sends an e-mail to notify the OEM of the new solutions. Then the engineering change sub-process is terminated, as shown in figure 8.

[Insert figure 8 about here]

6. Concluding remarks

Communication and engineering data consistency are the main challenges of collaborative product development. Thanks to the development of Internet and Web technology, it is possible to build up an engineering portal to solve the problem. The activities and business processes supported by the engineering portal covering from searching for potential partners, establishing collaboration and developing product collaboratively. However, these activities and processes must be effectively integrated and managed. In this paper, IDEF0 method is used to model the business processes for capturing the characteristics of problems and for identifying the functionalities required by the portal. The emphases in business process integration are put on the application of concurrent engineering principle and workflow management technology. Information integration is ensured by sharing a STEP-based product model and mapping STEP model to XML data. The solution for the coordination problem of a product development team is based on workflow management technology.

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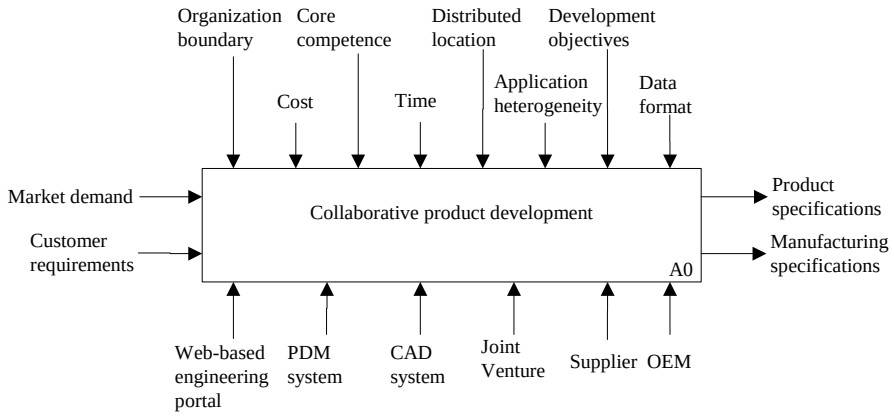
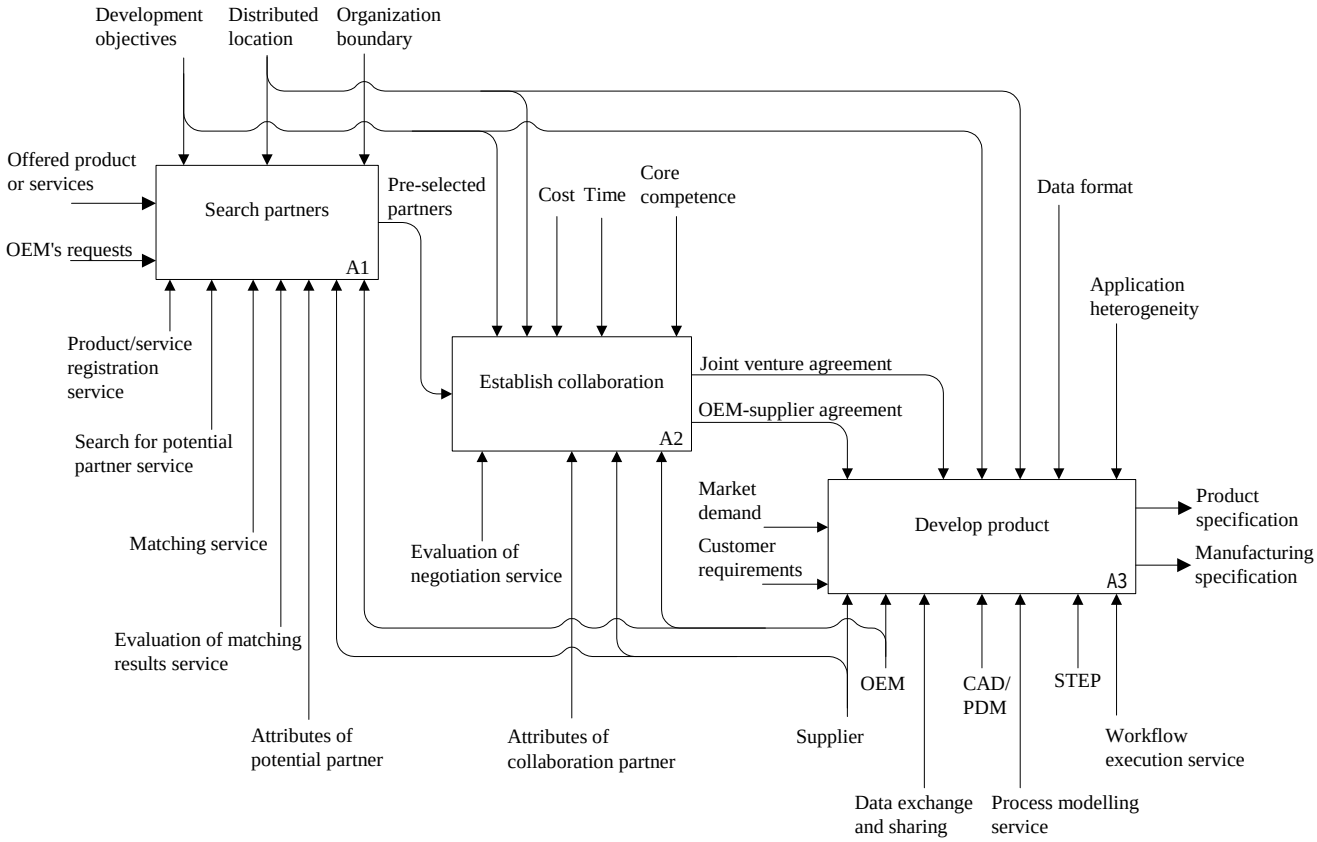
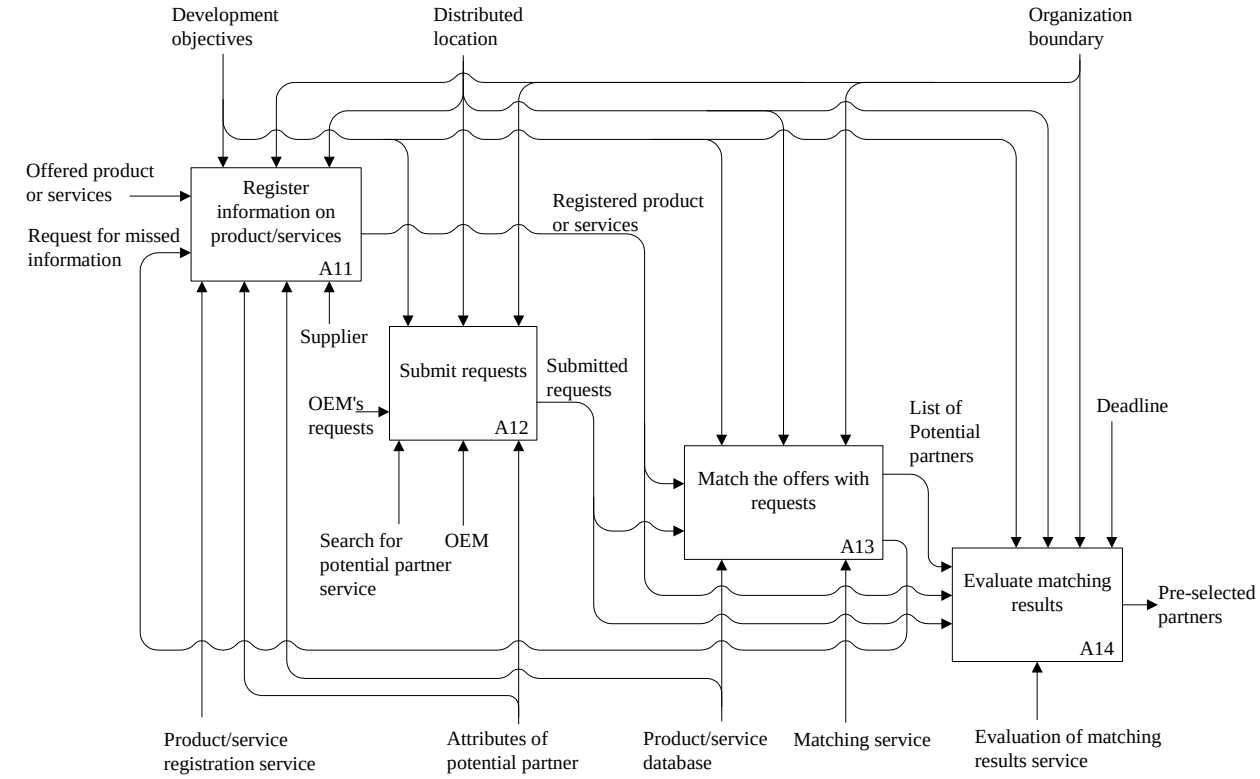
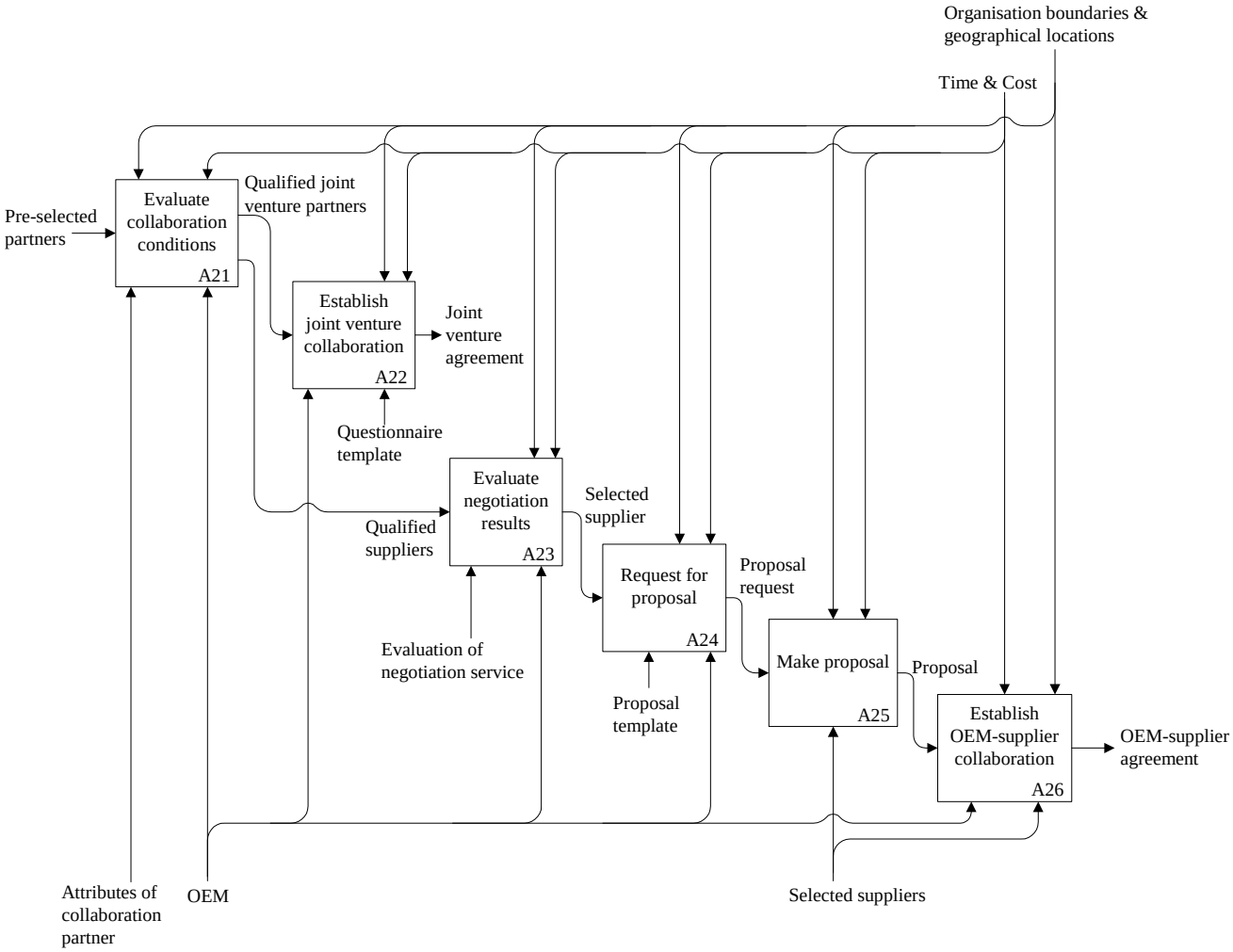
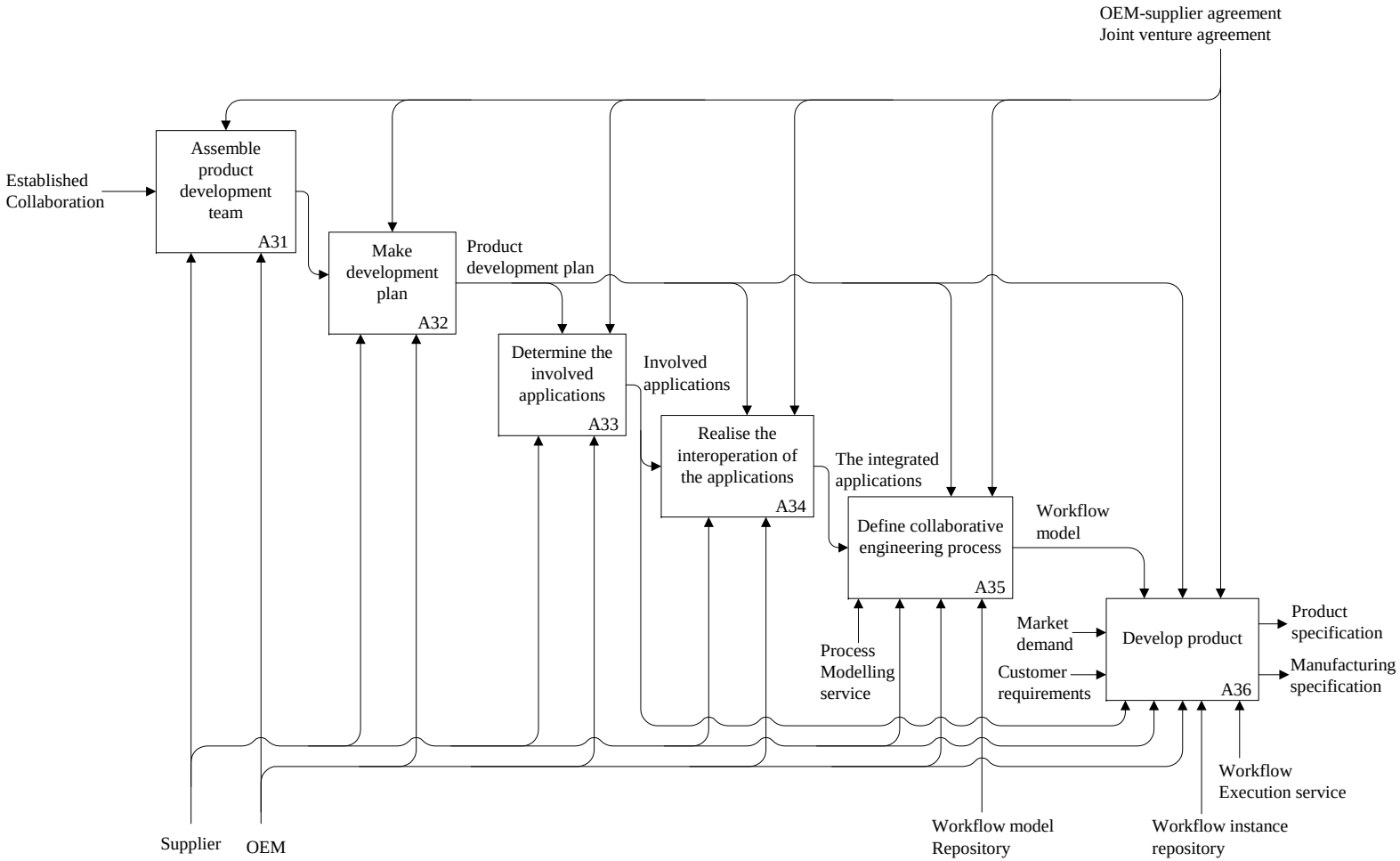
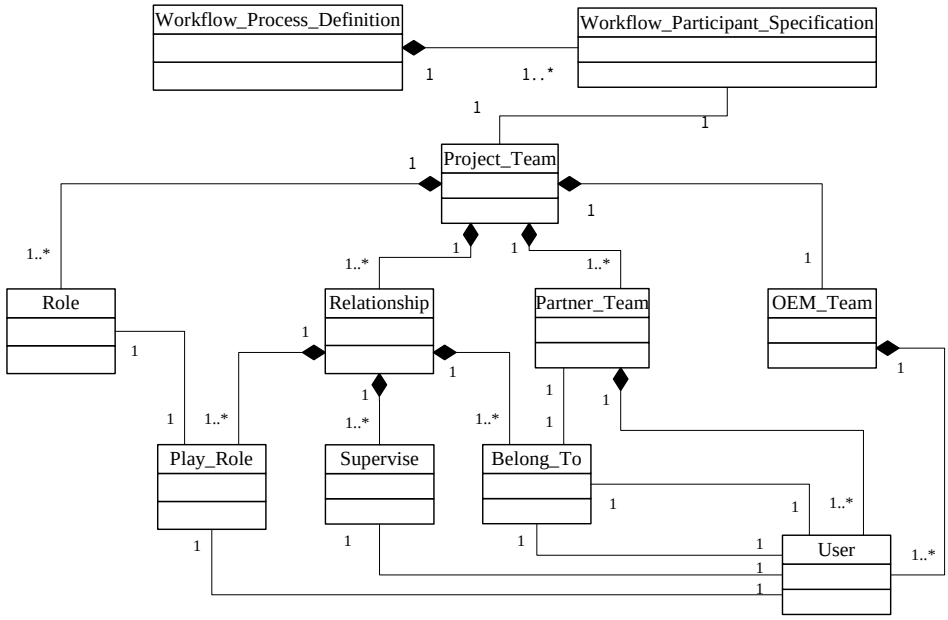

Organization boundary
Core competence
Distributed location
Development objectives
Cost
Time
Application heterogeneity
Data format
Market demand
Customer requirements
Collaborative product development
A0
Product specifications
Manufacturing specifications
Web-based engineering portal
PDM system
CAD system
Joint Venture
Supplier
OEM

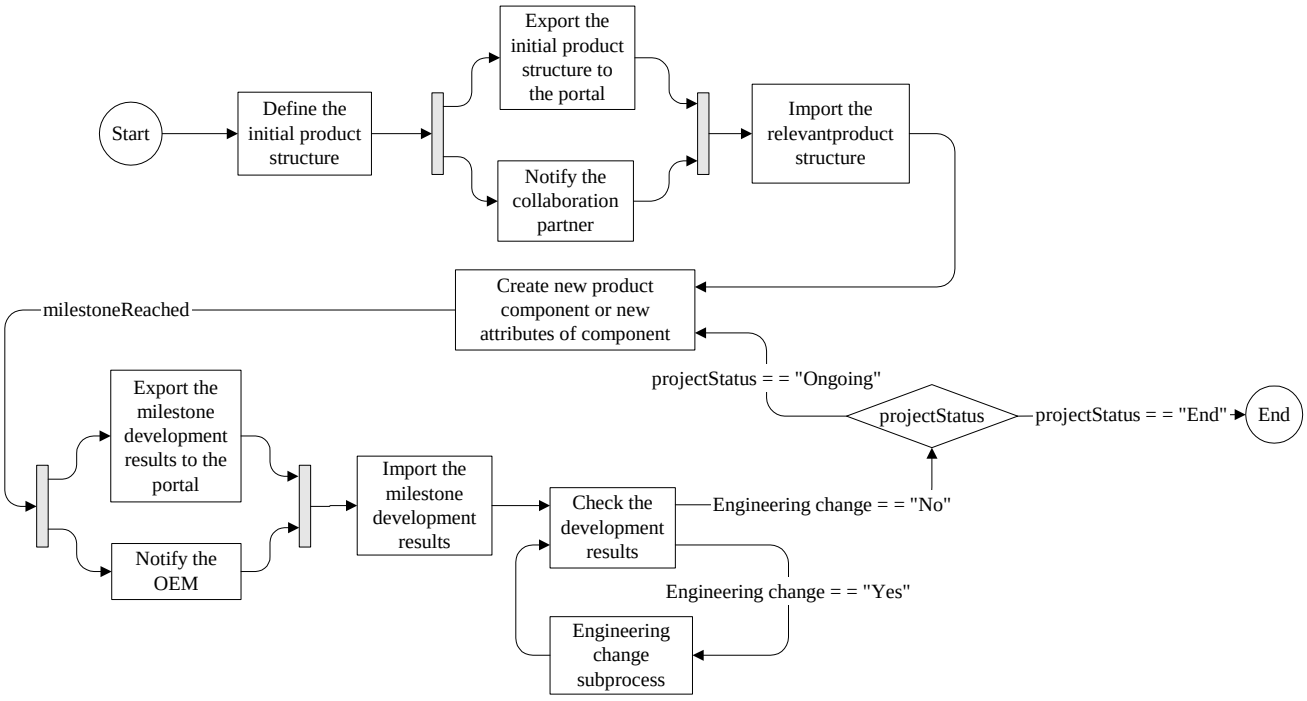

Development objectives
Distributed location
Organization boundary
Offered product or services
OEM's requests
Search partners
A1
Pre-selected partners
Cost
Time
Core competence
Data format
Application heterogeneity
Product/service registration service
Search for potential partner service
Establish collaboration
A2
Joint venture agreement
OEM-supplier agreement
Market demand
Customer requirements
Develop product
A3
Product specification
Manufacturing specification
Matching service
Evaluation of negotiation service
Evaluation of matching results service
OEM
CAD/ PDM
STEP
Attributes of potential partner
Attributes of collaboration partner
Supplier
Workflow execution service
Data exchange and sharing
Process modelling service

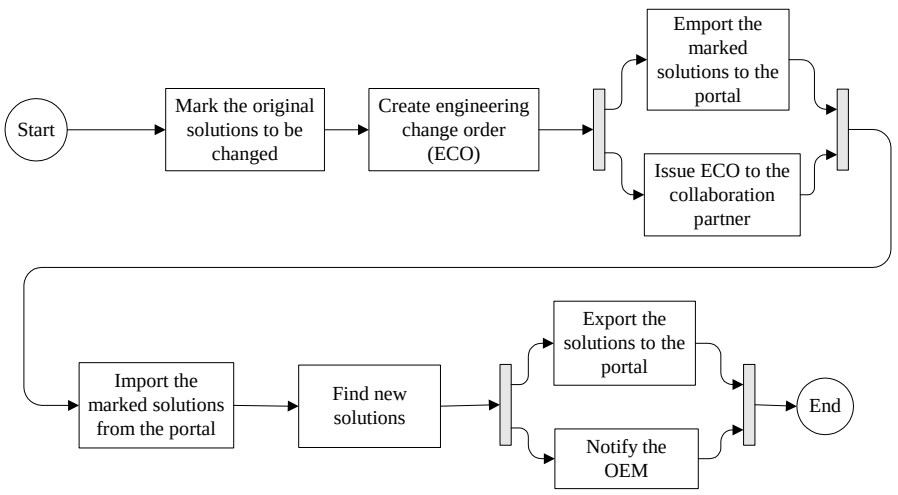

Development objectives
Distributed location
Organization boundary
Offered product or services
Request for missed information
Register information on product/services
A11
Registered product or services
Supplier
Submit requests
A12
Submitted requests
OEM's requests
List of Potential partners
Deadline
Match the offers with requests
A13
Search for potential partner service
OEM
Evaluate matching results
A14
Pre-selected partners
Product/service registration service
Attributes of potential partner
Product/service database
Matching service
Evaluation of matching results service


Organisation boundaries & geographical locations
Time & Cost
Pre-selected partners
Evaluate collaboration conditions
A21
Qualified joint venture partners
Establish joint venture collaboration
A22
Joint venture agreement
Questionnaire template
Evaluate negotiation results
A23
Qualified suppliers
Selected supplier
Request for proposal
A24
Proposal request
Evaluation of negotiation service
Proposal template
Make proposal
A25
Proposal
Establish OEM-supplier collaboration
A26
OEM-supplier agreement
Attributes of collaboration partner
OEM
Selected suppliers


OEM-supplier agreement
Joint venture agreement
Established Collaboration
Assemble product development team
A31
Make development plan
A32
Product development plan
Determine the involved applications
A33
Involved applications
Realise the interoperation of the applications
A34
The integrated applications
Define collaborative engineering process
A35
Workflow model
Develop product
A36
Market demand
Customer requirements
Process Modelling service
Product specification
Manufacturing specification
Workflow Execution service
Supplier
OEM
Workflow model Repository
Workflow instance repository


Workflow_Process_Definition
Workflow_Participant_Specification
Project_Team
Role
Relationship
Partner_Team
OEM_Team
Play_Role
Supervise
Belong_To
User


Start
Define the initial product structure
Export the initial product structure to the portal
Notify the collaboration partner
Import the relevantproduct structure
Create new product component or new attributes of component
milestoneReached
projectStatus = = "Ongoing"
projectStatus
projectStatus = = "End"
End
Export the milestone development results to the portal
Notify the OEM
Import the milestone development results
Check the development results
Engineering change = = "No"
Engineering change = = "Yes"
Engineering change subprocess


Start
Mark the original solutions to be changed
Create engineering change order (ECO)
Emport the marked solutions to the portal
Issue ECO to the collaboration partner
Import the marked solutions from the portal
Find new solutions
Export the solutions to the portal
Notify the OEM
End