Integration of Concurrent Engineering Business Processes via Service Oriented Architectures in the Virtual Enterprise

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Abstract: The paper will present results of the NETFRAME project (GRD1-2001-40435): "establishing a documented framework for on-line concurrent engineering and cooperation between large industrial auto and aeronautical companies and its suppliers". Within the scope of the EU funded GROWTH-project a comprehensive set of methods and tools is developed to support the improvement of the industrial concurrent engineering (CE) process in the virtual enterprise from both sides, industrial auto and aeronautical companies as well as SMEs serving as suppliers to the OEMs. To identify the state-of-the-art and key requirements within the concurrent engineering process an analysis was carried out to clearly outline the business scenario as well as the ICT architectures installed. Based on this, the project summarised the business and technical objectives as well as constraints imposed upon the required technological target architecture to seamlessly support the flow of manufacturing information between the diverse entities in this cooperation scenario. Presented within this paper are the project technological key results supporting this scenario. A technology architecture reference model and an XML model, focusing on tolerance analysis, to support and push the online and service-oriented architecture based cooperation of OEMs and their suppliers.

1 Introduction

Started as an economic requirement to increase outsourcing and to improve overall product performance by using the most appropriate expert teams in industry, concurrent engineering (CE) grew to a major industrial discipline enabling highly specialised and effective small and medium-sized enterprises (SME) to supply products and services to major industrial companies, organised in multilevel often global supply chain networks.

In this context, companies have to put special emphasis on their development towards knowledge intensive networked enterprises that are at the very heart of “tomorrow’s production systems”. Therefore, the identification and development of architectures, tools, standards and organizational processes linked with integration of networked and ICT supported (Information and Communication Technology) production activities in the virtual enterprise (VE) are key challenges [SG01]. Furthermore, these are the prereq-
uisite for highly effective supply chains and real production networks, as well as the basis for a reinforcement of the European industrial knowledge base and a better social acceptance, aiming at a user driven ICT and specifically eBusiness development approach.

The vendors/OEMs (Original Equipment Manufacturer) and large manufacturer are defining and driving the rules & terms of cooperation within the VE. Normally, suppliers and especially SME type entities have no impact on their definition, only forced to comply with the requirements of their customers. Moreover, when serving multiple large vendors/OEMs and manufacturers they have to follow and support different ICT environments as well as diverse execution of the CE business processes. This causes increased overhead costs to be borne by the suppliers, indirectly increasing the overall costs of the final product.

An approach towards a solution for this problem scenario in the VE environments, are service-oriented architectures supported by XML models. While they are extremely powerful, there is a need for agreed and harmonised ontologies based on extendable functional building block approaches, not driven by proprietary structures as well as accepted by the key players from both sides industry as well as ICT providers.

Therefore, the NETFRAME consortium, including automotive & aeronautics industries, SME suppliers and non-profit industrial associations, analysed the current manufacturing environment in CE processes in VE scenarios, starting with identification and validation of organisational Best Practices and key requirements. Besides the process improvement potentials, an enabling industry ICT architecture was elaborated, considering the CE Best Practices, advanced technology potentials as well as actual concerns of affected stakeholders. Moreover, with a focus on tolerance analysis activities which are carried out very early in the CE process, an initial XML model was developed, applicable for tolerance calculation but also coping with the requirements of other applications like e.g. CAD, CAE, or CAM which are used in subsequent CE processes.

2 Concurrent Engineering Environment

The elaborated industry ICT architecture for concurrent engineering environments of the NETFRAME project is based on a service oriented architecture approach. A service as [BA02] defines, presents a function that is well defined, self-contained, and does not depend on the context or state of other services. However, the paradigm of service oriented architectures (SOA) isn’t anything groundbreaking new anymore, but up to now neither widely applied in manufacturing industry nor extensively pushed by ICT vendors. There are many reasons for this situation; challenging aspects are the required innovations and new technology to implement SOAs. Much more hindering and key challenges in addressing these problems are:

- the lack of interoperability between the different systems that generate and provide access to the design and engineering data,
- the underlying ICT infrastructure, whether based on purchased products or custom-built solutions and
- the procedures used within the virtual enterprise of the manufacturing community.
Therefore, the main goal of the envisaged architecture, specifically addressing the CE processes, is to enable and promote the boundaryless flow of manufacturing information within the virtual enterprise, through defined as well as agreed organisational procedures and interoperability of manufacturing software to be used in the processes depicted in Figure 1.

Standards can help, but in a world of limited resources, consumers of information technology often face a choice between adopting standards to address existing problems, versus seizing a window of opportunity resulting from emergent technologies, in which ICT product suppliers have not yet established a dominant market position, and ICT consumers have not yet developed a large legacy of developed systems. Therefore, the project analysed both dimensions, on the one hand the key interest or concerns of the stakeholders, which can be used as general requirements for the development of supporting ICT. On the other hand the current technology environment to systematically structure the infrastructure enabling a component based improvement approach, aiming at an incremental and manageable change of the CE environment in VEs.

2.1 Key Interests and Requirements of Stakeholders

There are diverse stakeholders in the VE environments, which have to be considered when aiming at the introduction of new technologies or simply the limited change of interfaces or data management strategies. As main categories there are Business Management, ICT System Users as well as ICT System Developers and Administrators/Procurement experts. During analysis, these categories were divided in additional subclasses, resulting in 20 different types of stakeholders. Moreover, taking into account the VE environment, many organisations in the VE are incorporating most of those categories. However, these stakeholders from automotive and aeronautics industry were interviewed to identify their key interests. The results could be summarised as follows:

- **Business Management:** As expected by the project partners, the management function in the VE is highly oriented towards the QCS goals (i.e. Quality, Costs, Schedule), customer orientation and pushing the establishment of effective CE processes.
Real technology goals for a boundaryless information exchange or corresponding architectural questions are out of scope, only requesting for easy technology introduction and change. Therefore, there is a clear commitment of the business management function, but a real involvement in the realisation of the industrial ICT architectures in VE environments seems to be missing.

- **Users in the CE Process:** The users are also following the QCS objectives, to ensure the realisation of the demands of the management function. On the other hand they are especially focusing on the improvement of the data exchange and workflow management issues within the VE network. Therefore, they are the key driver of the industry ICT architectures.

- **ICT Developers, Administrators and Acquirers:** There is a clear commitment of this group towards the ICT world, searching for optimal solutions able to serve technology needs within the single organisation as well as managing the information exchange along the processes in the VE. But there is no clear connection to the core business or QCS objectives; only the ICT architects are trying to harmonise and coordinate the interests of the different parties. Moreover, in many cases the procurement experts and their teams are highly considering core technology requirements, but not widely involved in the definition and realisation of business and process objectives.

Taken into account this heterogeneous orientation of the different stakeholders, there is a high need to align the philosophies on a more strategic level, coupling and communicating the ICT strategy through the VE.

### 2.2 Current Technology Environment

The technical environment for manufacturing operations can be abstracted into three major areas: (1) Vendor/OEM environment, (2) Manufacturer environment and (3) Supplier environment. These environments are typically a networked set of workstations capable of processing a set of Computer Integrated Manufacturing (CIM) as well as Office applications. The OEM environment normally applies a standardised set of applications. The other have to operate various or a multitude of applications due to serving their customers within the VE. The applications are running in an environment of multiple servers within in a proprietary network, but increasingly becoming an Internet-based network, with the appropriate levels of and provisions for security. However, today this environment is not universally high-tech and actually is often a combination with traditional means from verbal transfer up to email, but offering advanced potentials by e.g. information exchange of agreed semantics and Internet web services. But requiring support with Security, which is handled electronically where possible, but often handled through physical security measures. Analogous to security, typically also quality is handled through manual procedures like inspection. Each of these is prone to error and would be greatly improved by sharing manufacturing information electronically.

However, if there is an electronic exchange, in many cases it can be depicted as in Figure 2. In this situation the electronic exchange is not robust, sometimes requires manual re-entry of data, and/or there are insufficient means to transfer semantics.
However, this exchange is not standard, nor complete as mentioned above. This causes numerous errors that plague the CE process.

3 Technology Architecture for Virtual Enterprises in Manufacturing

Based on the analysis carried out during the project, the major aim was to support VEs in the achievement of their business objectives (e.g. 100% fulfilment of customer requirements, faster design, reduced time to prototype, faster decision-making, reduction of waste). Therefore, based on [TO03], scope of the architecture is to support all phases of the manufacturing concurrent engineering process, while key considerations are:

- The exchange of information between software packages is of highest priority. This includes the exchange of information between software in the same domain (e.g., a CAE application to another CAE application), and the exchange of information between different software domains (e.g., a CAE application to a CAM application).

- The architecture must not require a replacement of current software, which would highly jeopardise the feasibility of a change. Therefore, aiming at an architecture which supports the necessary features for interoperability in a non-intrusive manner.

- Publicly accessible meta-data is built into the architecture, thus enabling the maximum reuse of the data interchange formats and descriptions. This publicly accessible meta-data should be developed and managed by an open consortium with representation from all the major constituencies, while the Internet plays a key role in the architecture, as it is a ubiquitous communication medium.

- There should be minimal incremental costs added to suppliers; e.g., supplier organisations should not be required to upgrade their software products. However, it is acceptable to have suppliers installing new modules that support interoperability.

- Manufacturing industry suppliers should not be obliged to become proficient in the use of tools demanded by manufacturers and vendor/OEMs, since it would jeopardise the widespread installation and user acceptance.
3.1 Architecture Principles

Based on the identified requirements of the stakeholders, the VE environments and the key considerations for the architecture, the following architectural principles were defined, aiming to facilitate the realisation of a feasible interoperability of manufacturing systems and applications, which benefits the manufacturing industry as a whole:

- The development of applications used across the VE is considered to be preferred over the development of similar or duplicative applications that are only provided to a particular organisation.

- Data is an asset that has value to the VE and there is a need for a cultural transition from "data-ownership" thinking to "data-stewardship" thinking, enabling to pass obsolete, incorrect, or inconsistent data to the appropriate personnel to take steps for its improvement, while data quality shall be continuously measured.

- Key aspect is to realise user access to the data, considering the timely & direct access, avoiding separated data islands and allowing a wide access supporting efficient and effective decision-making procedures.

- Each information shall have a trustee, which is responsible for accuracy and currency of the data, avoiding that data loses its integrity. Moreover, this requires for a consistent definition of the data throughout the enterprise, guaranteeing that definitions are understandable and available to all users.

Nevertheless, the technological diversity has to be controlled to minimize the non-trivial cost of maintaining expertise in and connectivity between multiple processing environments, while software and hardware should conform to defined standards that promote interoperability for data, applications, and technology, also taking into account data protection avoiding unauthorized use and disclosure.

3.2 Virtual Enterprise Technology Architecture

By adopting a service-oriented architecture in the VE environment, each of the services within the architecture can provide a specific set of generic functions that facilitate information exchange between applications in the manufacturing domain. This architecture is fairly straightforward, yet extremely powerful. Figure 3 provides a general overview of all the building blocks of the technology architecture that provide the services in the service-oriented architecture that, in turn, provides access to manufacturing information.

In Figure 3 there are various services and service interfaces. The services are connected to resources to which they provide access. The “Export Model”, an application-dependent service that extracts a requested data set (called a “model”) and encodes it in a document with a standard format (called a Standard Domain Interchange Format (SDIF)), and makes the resulting document available at a well-known and accessible address. The export document service retrieves the requested model, retrieves an SDIF Description, maps the requested model into the standard format, ensuring that mismatches are recorded according to the SDIF Description, and stores the document for retrieval by the requester. This service resides with the given manufacturing application.
The “Import Model”, also an application-dependent service that imports a requested “model” from an SDIF document, and converts the document into its own internal native format. The “Import Model” service retrieves the document containing the model to be imported, retrieves the SDIF Description to understand the meaning of the document, retrieves the SDIF Description of the target model (if different), maps the requested model into the target model format, determines how to process and report mismatches, and stores the new model in the native format. This service resides with the given manufacturing application.

Basic prerequisite is the SDIF directory a global service that provides directory services for SDIF descriptions. The “Access SDIF” global service provides create, retrieve, update, delete, and archive services to the SDIF Descriptions and Cross-Domain Maps. SDIF descriptions provide the standard description of how information is formatted to facilitate interoperability between applications in the same domain; e.g., CAE to CAE interoperability. Cross-Domain Maps provide a description of how one SDIF Description maps to another SDIF Description to facilitate interoperability between applications in different domains; e.g., CAE to CAM.

The global service “Access Exported Model” provides create, retrieve, update, delete, and archive services to named exchange documents that contain exported models. These documents are compliant with the SDIF Description standard and are the actual interchange interface between applications.

The Export Model and Import Model services connect to legacy applications. The legacy applications depict those manufacturing applications that create and manage manufacturing data, such as design data, engineering data, product data, etc. The legacy applications provide the access service to the legacy data.

### 3.3 Service Execution Environment

Figure 3 focuses on the key building blocks from a manufacturing application information exchange scenario. In order for this to work, a robust service execution environment must support each service interface. This service execution environment provides the necessary features for the environment to be secure, available, and reliable as presented in the following Figure 4.
Much of this approach is adapted from NCR’s OCCA [OCCA]. Each service interface operates in a service execution environment. The service execution environment provides necessary functions to invoke the service, including marshalling parameters, and ensures that only authorized requests are allowed. The service execution environment interacts with the host operating system environment to provide the necessary functions listed facilitating the overall technology integration, based on the defined SDIF.

4 Concurrent Engineering XML Model for SDIF Description

As presented before, the technology architecture employs SDIF descriptions to enable the information exchange. To put an SDIF description into practical application it requires an agreed and harmonised definition of data elements, taking into account domain specific as well as cross domain definitions. Moreover, to support the widely-used concept of web-services as well as to provide a usable definition which is described by itself, the project aimed at the elaboration of an XML model. By this it will also be possible to add further definitions for the continuous integration of the SOA.

4.1 XML Model - Key Aspects

Based on the technology architecture and the analysis of the business environment, for the SDIF description, an initial XML model was prepared, incorporating the interrelationships of the key objects in the CE process as presented in the following Figure 5. Moreover, to elaborate an appropriate XML model, the information was structured according to its purpose within the CE process, classified as follows: (1) Content data for e.g. analysis, calculation, refinement or presentation, (2) Data to structure or manage the content, (3) Data to initiate activities within the CE process and the VE workflow (4) Data for the “service execution environment”.

Figure 4: Target Service-Oriented Architecture - Service Execution Environment.
Following the basic data structure as presented in Figure 5, the amount of data within the concurrent engineering process can rapidly grow beyond limits which do not allow for a continuous exchange of all available data in short frequency. Therefore, it only seems to be feasible to exchange data (i) which is explicitly required for an activity in the process as e.g. a calculation or analysis and (ii) which contains changes to information which was already exchanged before.

Moreover, data exchange within processes is connected to the integrated workflow, spanning diverse entities in the VE environment. To avoid unnecessary data exchange, diverse use cases can be defined, grouping data elements, classes or constructs by exchange scenarios according to the tasks, activities, sub-processes or processes. Based on such use cases, it can be decided how to group data elements and which elements are required or optional. The following basic use cases or exchange scenarios were defined:

- Transfer of the complete data set which is available within the process.
- Only transfer of changes made to the data.
- Transfer of predefined sub-sets of complete data which are defined in accordance to the use cases within the process.
- Transfer of complete information structures with mandatory and optional elements, to be filled in accordance to each specific case.

However, the basic data elements (see Figure 5) have to be detailed in accordance to the use cases as well as to their purpose within the process, and subsequently describing the SDIF, taking into account domain specific and cross domain CE process definitions.

4.2 Focus of the SDIF Description

Especially to take into account cross domain definitions in CE processes, the project is focusing in its early phase on an analysis of the tolerance analysis process, which is an accompanying task along the other CE processes. This focus was set, since:

- tolerance analysis affects styling, design, engineering, manufacturing planning and tooling activities, while it requires input from those processes for calculation studies, which are checking fulfilment of defined quality criteria,
- tolerance analysis already starts in the very early conception phases, when no CAD or engineering model exists and is seamlessly shifting to tolerance management which is also a key engineering task in the later CE phases,
- tolerances are directly affecting design of both product components as well as manufacturing tools at the production line, requiring an integrated and combined view of different process experts as there are e.g. design, engineering, management and procurement while aiming at a “global optimum”,

- tolerances are defined by the designer, the engineer as well as the manufacturing expert, separately initiating re-calculation, requiring an integrated access to the calculation engine and

- tolerances are defining interface conditions between sub-assemblies or components assigned to different entities in a VE, valid for automotive and aeronautics industry.

Therefore, this area offers a key opportunity to drive the stepwise and more formalised collection and archiving of engineering data, compatible to later tasks as there are e.g. product data management, logistics or quality assurance. Moreover, the objective to improve the “automated electronic data exchange” will facilitate the realisation of calculation studies already in the early CE phases. This will contribute to avoid compatibility problems, often occurring in the later full engineering design. As business objective, it is estimated to achieve direct effort savings within the process and indirect savings by a reduced time-to-market.

4.3 Approach and Sources for the Information Model Development

When developing the information model, the project was aiming at a reuse of existing experience gained and references; not to reinvent the wheel. The individual knowledge of the project partners in their VE environments was collected and the project used existing standards and modelling approaches. Namely the DML model [DML04], the ENV 12204, the ISO 9001 and ENGDAT [OD02] were key references for elaborating the initial information model.

In addition, work was performed to develop a draft model for the representation of tolerance information [CH03], which is based on DML. It is adding further elements for the structured and complete description of product elements allowing to define assembly information that can be used to exchange such information between diverse applications. But especially when analysing current data structures, the following key aspects for the support of a service execution environment are actually not addressed:

- Especially in the early CE phases several designs, multiple concepts, instable quality criteria or manufacturing alternatives have to be considered. This information often only exists as fairly unstructured textual or graphical often incomplete and inconsistent information; requiring the process knowledge and experience of the VE employees to acquire and transform this information in electronic data elements, supporting the service oriented data exchange, analysis, calculation or simulation.

- The exchange of engineering data especially in VE environments with its diverse stakeholders imposes additional requirements on the data request, change and configuration management. Therefore, besides tool functionality, it was identified a lack of data elements for information management, facilitating the e.g. check of actual versions, selective transfer or access to data as well as supporting security services.

Therefore, complementary to the referenced sources, also existing structures and applied approaches at prototype VE environments at project partner sites were used. Accompa-
nying, the model was distributed for a consensus building process, while the partners decided for a free and open source approach to push the adaptation of the model.

### 4.4 Initial Information Model

Based on the analysed sources and the terminology respectively vocabulary at the industrial partner sites a first taxonomy according to the type of data (e.g. organisational, product or process information) and a list of terms was elaborated.

Moreover, the ENV12204 and ISO 9000:2000 were considered concerning the validation, verification and structuring of the important terms w.r.t. the organisational and modelling dimension, also including a mapping of the important terms to different sources. This was the basic reference for the elaboration of the “final set of terms” and the object oriented data model. This data model or rather initial Ontology was used as basis for the further consensus building process between the industrial automotive and the aeronautics partners. Serving also as reference for the involvement of interested parties. Therefore, the initial ontology was presented on a high abstraction level, presenting the Big Picture and strategy of the model as presented in the following Figure 6.

![Figure 6: Entity Relationship Diagram of the initial ontology.](image)

There are several quite extensive sub-sets defined, especially w.r.t. the product information. To facilitate the refinement of the model the project is actually elaborating and refining specific use cases for the VE environment, aiming at the support and improvement of specific activities in the CE processes. The full XML Model is available via [NE04]: [http://www.netframe.org/](http://www.netframe.org/) - For the preparation of the model, XML schema were prepared, using the XML Spy tool, highly facilitating the graphical modelling, also fairly easy to understand for the engineers within the CE process in the VE.
5 Conclusions

As proven by case studies from industry, benefits and savings of an optimal enterprise architecture can be millions of Euro [BL04]. However, besides the executive support and user involvement there are several prerequisites for success. As there are diverse existing systems, interfaces and stakeholders, appropriate architectural concepts as the presented one are necessary. A key factor is not to search for complete replacement of the existing infrastructure but to apply a feasible methodology as e.g. [TO03] allowing for the migration of systems, interfaces and architectures. Moreover, besides solution independent models, especially the VE requires for agreed and new ICT solutions, securing distributed computing, facilitating configuration management and integrating data structures. On the top of that, new licensing approaches (i.e. free and open source software) are offering robust solutions at minimal costs.

Moreover, the NETFRAME partners are aware of the costs necessary to define and promote data models, but are convinced that a pay-back on the long term is achievable, since de-facto industrial standards will highly facilitate integration of processes as well as ICT in the VE.

6 References


