

Towards Seamless Product Structure Information Integration

Paavo Kotinurmi¹ and Ilse Becker²;

¹ *Researcher, TKK, Paavo.Kotinurmi@tkk.fi*

² *Specialist, Valmet Automotive Oy, ilse.becker@valmet-automotive.com*

Although B2B integration is nothing new, interoperability is still a big issue in product data communication. However new technologies are introduced and existing standards evolve to better support all operations to improve the situation. In this paper we introduce a product structure information exchange case from automotive supply chain. Current integration has proprietary XML interface between partners and the integration has constantly errors requiring manual checks for the incoming information and interface have been inflexible to changes in the systems. We review relevant technical and content standards to solve this case. The traditionally used message validation technologies such as DTD or XML Schema lack the expressive power to solve some problems and thus we present a practical case for new semantic web service technologies.

Keywords: Automotive industry, B2B integration, product structure information, semantic web services, standards

I. INTRODUCTION

The Automotive industry has a long tradition in systems integration related to order delivery processes, where the first Electronic Data Interchange (EDI) standards were built already in the 1970s. However, the lack of integration is still a big challenge. Especially for contract manufacturers, as they have to integrate both with their Original Equipment Manufacturers (OEM) and with component suppliers. Furthermore, the contract manufacturers are included already in product development phase to improve the manufacturability of the product. This results in need to transfer a lot of product structure data. The OEMs have heterogeneous systems and power to dictate integration details causing the flexibility challenge to contract manufacturers. A study in the US automotive supply chain [1] estimated that one billion dollars is yearly lost due to poor interoperability in communicating product data between design systems alone.

There is a lot of manual work involved in the current integrations for product data. This is partly due to lack of standards or lack of expressive power in the current technical standards underlying the content standards. EDI standards have very limited support for validating the messages. The newer XML-based standards have easier validation mechanisms, but they have also limitations in what can be expressed. It is a truism of computing that to map between dissimilar data structures a more powerful data representation is needed [2]. The new formal semantic

web service technologies introduce languages to provide more powerful validation. Here we compare the approaches of using existing traditional XML standards and semantic web service to tackle the practical challenges in integrating product structure information between an OEM and a contract manufacturer.

We also take a look at prominent electronics and automotive industry standards as both industries are advanced in their integration solutions. Electronics and automotive industries have developed own standards for B2B integration. However, the industries are getting closer to each other as both increasingly use same electronic component suppliers as the new car models have increasing amount of electronics. We make initial comparison of the content of product structure data in RosettaNet, STEP and Odette ENGDAT standards. We look how they support the exchange of product structure information. Methodologically this work follows guidelines of design science research in information systems [3] as an IT solution to practically relevant problem is the goal of this study. However, our solution is still a concept and thus the evaluation part of the research is still very limited.

This paper is structured as follows. Section II presents a case for product structure integration from a current situation. Section III introduces base technologies in the integrations and presents how the different B2B standards fit the requirements for the product structure exchange. Section IV discusses the initial solution to the problem using XML Schemas and semantic web service technologies. Section V positions this to related work and Section VI discusses the expected benefits. Finally, Section VII concludes the paper.

II. CURRENT SITUATION

Automotive industry designs the car and its modules currently merely in 3D models, which cannot be utilized without the product structure information. The 3D models are combined with the positioning in the coordination system, which is a part of the structure data. The models are needed in all planning including packages for the parts, tooling for the production, simulating the production processes and measuring the parts and constant engineering change processes. Furthermore, contract manufacturers are continuously calculating offers for the quotes they get from OEMs. To be able to do the calculating properly the manufacturer needs to get the 3D models with their

structures as input.

The product structure data is very challenging for integration, while it can vary a lot depending on the systems and companies producing them. The information includes distance and position information. The different design systems use support differing accuracy to represent decimal numbers and thus export the position information differently. If the companies would have similar design systems, the replication of the databases could solve integration needs. However, as OEMs use different systems, the contract manufacturers should need all possible similar system, which in practice is often impossible due to costs.

Figure 1 shows the current situation between an OEM and a contract manufacturer. The integration uses mainly EDI or custom ASCII-based integration between the order management systems. This integration is characterized by lots of small messages exchanged uses Odette File Transfer Protocol (OFTP) using network operators instead of public Internet. The 3D model integration uses dedicated servers to handle the potentially large CAD files. This is based on OFTP-based ENGDAT protocol that is specialized for design data files exchange.

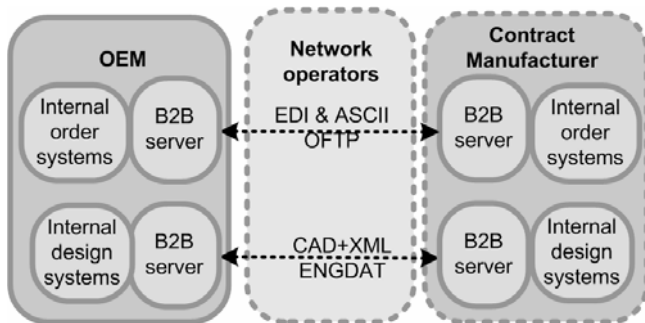


Figure 1 Current information exchange

The product structure currently comes in a proprietary XML message resulting from exporting data from OEM's product design systems. However, this integration has constant problems from the contract manufacturer's point of view as they need often to manually fix the incoming data in order to get the information to their own design systems. This is manual work resulting from poor interoperability considering position matrix information. The position matrixes have inaccuracies as the sending system has less meaning numbers in defining the matrixes. The contract manufacturers design systems report errors when the square sums of row and column values are not accurate enough – the square sums of columns and rows should be exactly one or otherwise the systems do not take in the models. Currently an IT administrator needs to manually check to see whether the error was significant or not and then manually take the files to their internal systems. Most of these error situations are actually non-significant but all this results that the person needing the files need to wait for the IT administrator to manually check these files before they get to work on the information. Table 1 shows an extract of XML file position

matrix information coming from OEM's systems. The extract also contains state and time information that comes directly from the OEM's product design application, as well as the position information. The timestamp is in UNIX datetime format. Some information has been omitted from the example and for instance name and identifier information have been removed as for the problem the specific part is not important. The square sum of the coordinate (x,y,z) rows and columns should be 1 - in the example they are not if there are more than 11 decimal used for accuracy. The contract manufacturers system expects the accuracy with even 17-18 decimals but the product design management system at the OEM only use 10-12 decimals. This creates sometimes error situations that are not too significant but currently the contract manufacturer cannot detect these situations automatically.

TABLE 1 XML INSTANCE EXTRACT

```
<object state="Aktiv" timestamp="1088171275"
xx="0.0366871538" xy="-0.0526438196" xz="-0.9979392171"
yx="0.9993267998" yy="0.001932653" yz="0.036636213" zx="0.0"
zy="-0.9986114826" zz="0.0526792833"/>
```

Problems in this integration interface were highlighted as a recent design system upgrade by OEMs resulted in slightly different XML structure file. OEM did not test with the contract manufacturer before implementing the changes nor was there any data validation in place. So changing attribute name and removing two other attributes broke the integration at contract manufacturer's end. This motivated this study to improve the current situation. As the current B2B interfaces are not based on standards, the integrations are very specific with the systems. Furthermore, the problem with position matrix is still there although the proprietary file has been fixed to make the basic B2B integration work.

In this paper, we compare different standards to establish standard message interface that does not need to change as internal systems or their versions are upgraded. We further describe, how the currently unsolved error situations with position matrixes could be solved using more expressive languages for validating the incoming information.

III. KEY TECHNOLOGIES AND STANDARDS FOR B2B INTEGRATION

In this section the main standard building blocks used for B2B integrations especially in automotive industry are introduced. First the underlying technologies EDI and XML are handled and also new and semantic web service technologies are introduced. Then relevant B2B standards supporting the interoperability are introduced.

A. Electronic Data Interchange

There are two main EDI syntax standards in use. The first standards of U.S. version of EDI, American National Standards Institute's (ANSI) X12, were published in 1983. The EDI for Administration, Commerce and Transportation (EDIFACT) was originated in 1985 to address the problems caused by different standards on both sides of the Atlantic.

The EDIFACT standard development is United Nations (UN) lead. The X12 syntax is the most used EDI syntax in North America, while EDIFACT is the dominant standard in the rest of the world. Besides, there are EDI formats, such as Verband der Automobilindustrie (VDA), that have been developed before these international EDI syntaxes.

UN/EDIFACT syntax (ISO 9735) defines the structures that are used for interchange of data. The UN/EDIFACT syntax, in its earliest versions, used batch data transfer and predefined, structured messages. Later capabilities for interactive data transfer and transmission of binary data have been added together with a set of comprehensive security mechanisms. When EDI was introduced, the information exchange was expensive. Therefore, the EDI syntax is very compact in size. This makes them hard to read and maintain as codes are used to represent complex values. The EDI messaging uses often Value Added Networks (VAN) operators although EDI does not limit transport mediums. These special connections have been quite expensive. The recent advances in EDI messaging standards, such as EDIINT specifications have enabled companies transacting EDI over Internet rather than the pricier VAN making it affordable for smaller companies

The automotive industry's use of EDI standards and the benefits obtained have been documented [4] [5]. EDI is based on predefined message contents and the validation for it is not supported directly by the standard but rather it is a part of applications "parsing" EDI documents. With EDI, there are different standards defined in Europe with Odette based on EDIFACT syntax since 1996 and US with Automotive Industry Action Group (AIAG) based on X12 syntax since 1985. Both Odette and EDIFACT have had their further development of the standard to XML technologies [6]. Also ODETTE and AIAG has been having some collaboration in this, but the concrete common specifications are missing.

B. XML technology

XML was introduced in 1998, and since it has been claimed to be replacing EDI in B2B integration. Many standardization activities have shifted from EDI development to XML technologies. The XML technologies make it easy to validate the structure of XML documents using Document Type Definition (DTD) or XML Schemas. A DTD specifies the structure of the XML message by defining the elements of the message, occurrences of the elements and a hierarchical order between the elements. XML Schema defines same issues to DTDs, but it has more expressive power. XML Schema offers a number of built-in datatypes to support how date values or currency enumerations should be in the valid messages. It is also possible to present cardinality constraints, such as choosing exact amount of the optional elements or having choice between possible elements. There are also other useful XML applications for B2B integration to make it simple to produce, transform and connecting to service end-points. web service technologies, SOAP and Web Service Description Language (WSDL) make it easy to call services from different applications as the SOAP clients

generation is partly automated from the WSDL description making it fast and easy to make such integrations.

C. Semantic web service technologies

Semantic web service technologies tackle interoperability by introducing rich formal languages for describing the integration end-points. They extend the capability of current web service technologies that basically only help in messaging and do not support defining the content exchanged. Semantic web service technologies have more expressive power than current XML Schemas. If there are complex relations between element values in the document, the XML Schema lacks the power to define the validation rules needs and thus custom program code would be needed. Using a declarative language to specify validation rules is a good option due to easier maintenance.

The Web Service Modeling Ontology (WSMO) provides a conceptual model and a language for describing the relevant aspects of web services [7]. The goal of such markup is to enable the automation of tasks involved in both intra- and inter-enterprise integration. The markup of services according to the WSMO conceptual model is expressed in the Web Service Modeling Language (WSML) family of ontology languages [8]. WSML consists of a number of variants based on different logical formalisms. WSMO is the underlying model of the Web Service Execution Environment (WSMX) [9]. WSMX is an integration platform conforming to the principles of a Service Oriented Architecture (SOA) which facilitates the integration between different systems. The languages such as the Web Ontology Language (OWL) or the Web Service Modeling Language (WSML) have the needed expressive power to assign rules for documents for which the DTD or XML Schemas are not enough.

D. Standards for product structure information

There are several content standards for integrating heterogeneous enterprise information systems that are defined on top of EDI or XML technologies. Standards hold the promise of reusing integrations with different partners and they make the integrations more loosely coupled from specific applications used. As the standards define B2B integration interfaces between the partners, the partners can change their internal processes and information systems without a need to change the B2B integration interface. Here we concentrate on message interoperability making sure that parties understand the exchanged information as guided by the standard. We also mention the standards used to secure transportation of the messages.

Electronic Data Interchange (EDI) standards, such as VDA, AIAG and Odette have been around over decade and are widely used for B2B integrations in the automotive industry. There are also many active XML-based standardization efforts for automotive industry. The amount of different standards is a challenge as it creates a problem of deciding on what standard to base own solutions. If multiple standards are needed for logically similar interactions, it decreases the value of having the standard.

Implementing support for any standard is a non-trivial task as significant effort is needed to ensure that the systems can produce and consume the standard documents [10]. Here we present Odette ENGDAT and STEP as prominent standards for the automotive industry and product data exchange. We also introduce RosettaNet that is very important in the electronics industries and it also defines standard messages for product development phase communications.

E. Odette ENGDAT

Odette ENGDAT (<http://www.odette.org>) is a standard for transferring product data between organizations. Odette International is a standardization body formed by the automotive industry. The ENGDAT defines an envelope, which wraps the engineering data. The content can consist of several files, such as CAD, MS-Word, XML and STEP. The content of the files stay as they are, the ENGDAT envelope is only telling, what kind of files and what are the names of them that it is transferring and thus does not standardize the meaning of the engineering data messages exchanged. Odette defines also EDI messages and is working on XML-based definitions for the needs of automotive industry. Odette is mainly based in Europe whereas AIAG and JEDAC represent similar efforts in US and Japan respectively.

As ENGDAT only defines the envelope, it does not help in standardizing the content needed for information exchange. Content definitions and validation support would be needed to help in the case situation.

F. STEP

STEP - Standard for the Exchange of Product Data - is also an ISO standard (ISO 10303). The STEP standardization started already in 1984 and first standards were published in mid-nineties. In 2001-2002 a second major release of STEP was released. STEP includes a number of application protocols (AP) for different industry sectors based on common integrated resources and provides also solutions for exchanging product models. STEP effort has created EXPRESS language with textual and graphical notation to define STEP standards.

STEP AP 214 titled "core data for automotive mechanical design processes" is used currently in parts of the automotive industry for exchanging design data.

STEP uses own data formats that are not easy to read and understand. XML was not around when STEP development began. Only recently there are specifications how STEP EXPRESS schemas are represented in XML. STEP is concentrated in providing standards for messages and does not introduce any solution similar to Odette ENGDAT for secure messaging. STEP has been a global effort.

STEP seems potential but the cost of the specifications has slowed the efforts so far to get in-depth understanding what problems it might solve. STEP is in use in automotive industry for similar purposes but e.g. whether it can help in position matrix is still unknown. Most probably it cannot solve all the issues as the problems with the position matrixes. Still it might well provide support for describing

the information needed in the message.

G. RosettaNet

RosettaNet (<http://www.rosettanet.org/>) is an electronics and information technology industry-driven consortium for B2B standardization. The most important components standardized in RosettaNet are Partner Interface Processes (PIPs), dictionaries and RosettaNet Implementation Framework (RNIF). The PIPs standardize the message contents and the processes, where the messages are exchanged. The PIP messages are described by using DTDs and additional message guidelines or XML Schemas with the most recent PIPs. The messages are similar to e.g. what Odette defines for automotive industry. The RNIF is functionally very similar to ENGDAT as it acts as the envelope to send the PIPs between the partners securely over the Internet and accepts all kinds of files as attachments. RNIF is typically implemented directly by the companies and therefore network operators are not needed for the information exchange.

Compared to many standardization efforts in automotive industry, RosettaNet is really global in its reach of the IT industry. All the standards are available as free downloads from the Internet.

RosettaNet can be used to product development phase communication [11]. For example standards for material composition are already used in companies who also provide electronics for automotive industry. RosettaNet have partly defined needed terms in its data dictionaries to support date and time representations and product life-cycle information. However, the required definitions for position matrixes are not included in RosettaNet dictionaries and messages respectively. Furthermore with the current technologies the validation needs of contract manufacturer are not covered with the basic RosettaNet technologies. For 3D model exchange RosettaNet does not provide currently any special solution, basically just document transfer as for any other binary document.

IV. PROPOSED SOLUTION

In this section, we propose a solution for the case. The solution should be based on standards to provide common terminology (ontology) for the messages exchanged and would already solve issues related to tight-coupling of existing applications. The benefit of standard-based approach is to make the integration less specific to current version of the integrated systems used so that system upgrades would not break the integrations. However, the Odette ENGDAT or RosettaNet do not cover all the information needed for exchanging product model data. About STEP AP 214 we cannot say anything definite yet without further analyses.

Here we present a solution of own schemas done according to currently exchanged XML messages to show what XML Schema can check automatically from incoming information. We further discuss how different existing standards fit with the solution and a case for semantic web service technologies to tackle the more complex validation

needs.

XML Schema as in Table 2 can help to check that the date is in agreed format or that the individual values are decimal numbers between -1 and 1. The schema can also check that the timestamp is a numeric value as it should in UNIX timestamps and that the life-cycle information in the model is according to the enumerations. For checking the square sums XML Schema cannot be used or in general that if another value within the document further constraints. So the problem with position matrixes is still the same. The XML Schema is not expressive enough to check complex contents such as position matrixes although these checks already can automatically catch erroneous inputs.

TABLE 2 XML SCHEMA EXTRACT

```
<xs:element name="objekt">
  <xs:attribute name="state" type="lifeCycle"/>
  <xs:attribute name="timestamp" type="xs:integer"/>
  <xs:attribute name="xx" type="coordValue"/>
  <xs:attribute name="xy" type="coordValue"/>
</xs:element name="objekt">
<xs:simpleType name="coordValue">
  <xs:restriction base="xs:decimal">
    <xs:minInclusive value="-1"/>
    <xs:maxInclusive value="1"/>
  </xs:restriction>
</xs:simpleType>
```

Standards are needed to guide how information should be presented. Otherwise e.g. considering the life-cycle states, the systems can present a same state using different terms (active vs. aktiv) or semantics. As semantic difference different companies can have different meaning for attribute active – for one it can be approved for production for others just that the 3D model is checked. Also timestamps should be guided as the dates can be put differently in different systems e.g. considering time zones and one needs to know whether the timestamp refers to the last change of 3D file or file approval. Standards such as RosettaNet, STEP or Odette can guide in these semantic interpretations, the companies just would map to the common standard data model and this isolates further changes of the application to not change the integration interface.

Table 3 presents an extract of ontology in WSML that can check that the square sums of rows and columns are within accepted limits. For WSML reference, see [8]. This is possible as WSML language contains built-in functions that enable performing needed calculations as shown in the example. This enables that designers can specify acceptable limits for the incoming information. The expressive power enables thus automatic checking of constraints.

TABLE 3 WSML EXTRACTS

```
// Count square sums of coordinates
wsml#numericMultiply(?xx2, ?xx, ?xx)
wsml#numericMultiply(?xy2, ?xy, ?xy)
....
// sums up the rows and columns.
wsml#numericAdd(?xrowt, ?xx2, ?xy2) and
wsml#numericAdd(?xrow, ?xrowt, ?xz2)
..
// Check that the values in acceptable limits 0.99999 < value < 1.00001
wsml#numericLessThan(?xrow, 1.00001)
wsml#numericGreaterThan(?xrow, 0.99999)
..
```

The existing XML messages need to be translated to ontology language as in [12, 13]. This is design-time activity that needs to be performed once. Then reasoners supporting WSML can perform the calculations to check the validity of incoming information at run-time. This approach is similar to one used in [12, 13, 14].

V. RELATED WORK

The general benefits of integrations are well documented. The benefits of EDI technology has shown the impact of integration and measured the savings. Mudhopadhyay made a thorough study at Chrysler, where the benefits of EDI integration amounted to more than 100 \$ per vehicle produced [5].

There is also already work done discussing the use of semantic web services to enhance current automotive B2B standards. Anicic et al. [12] describe how current XML Schema-based automotive B2B standards (AIAG and Star) are described using Web Ontology Language (OWL) based ontology to tackle the interoperability between both standards. They translate the XML messages to OWL instances to perform the equivalence tests between elements and enable checking better that the messages comply with the restrictions. Their experiences indicate that currently available tools for semantic web are clearly not sufficiently robust and scalable to warrant risk-free development to support industrial interoperability efforts. However, the rate of maturation and adoption of these tools is encouraging and it seems that these issues of robustness and scalability may be addressed in the near future. This is similar to our experiences that the tools are still developing and full support for complex operation is still lacking.

The general benefits of semantic web services to B2B integration has been studied. Preist et al. [10] provide a case on managing supply chain during the integration life-cycle. [13] present how RosettaNet standards could be enhanced using more expressive languages. Both discuss how RosettaNet and EDI standards can benefit from the new technologies.

Tanaka and Kishinami [14] study Product Data Quality (PDQ) and concentrate on a quality diagnosis method of the shape data of the product model. The file is described with STEP technology using EXPRESS-X language, which is the mapping language between STEP models. The geometrical shape compatibility between two different interoperating systems is important as is the structure information for the placing of the model in the coordinate. They propose also a certification data model of the product

data to help in the validation process. It helps to validate that the incoming model information is accurate enough so that the receiving system can check it. This certification data is described with XML and using commercial EXPRESS-X execution environment. Getting such information from the OEM make the process of checking model correctness straightforward and the EXPRESS-X environment could even have similar functionality to the WSML validation proposed to check the acceptable tolerances in the 3D model information.

VI. DISCUSSION AND EXPECTED BENEFITS

It is unrealistic to assume the mapping problems with heterogeneous systems go away quickly. Mapping particularly from less expressive to more expressive can cause problems as the use of decimals here presented. The integration the other way would be simpler as the less accurate system would not have similar problems in reading in the data.

However, there are technologies to better manage the heterogeneity. The new technologies make it easier to introduce rules to tackle the problems now requiring manual handling. For these rules to work in the case, the domain experts need to assign the acceptable limits of acceptable values for position matrixes. This includes codifying the rules related to there expert area for automatic checks, and the situations where a manual handling is really needed, which is about 10% of the current error situations. The current situation means unnecessary manual activities and they slow down the processes as the information needed does not reach the users requiring the information before these issues are manually solved. This waiting has more significant cost effects than just the avoided manual activities as engineering change processes in the company networks increase the need of product data communications making manual checking harder to scale.

Even with semantic web services, common understanding of the terms is needed. Selecting and negotiating the use of standard can be time-consuming compared to pair-wise agreements, but it also allows extensibility. The problem is that often standards do not define readily all the needed concepts for messages causing still problems fitting the information to the standards.

The knowledge of semantic web service languages is small and the languages and execution environments, such as WSMX, to support all the features of these languages are still under active development. Same applies for the tools, such as the Web Services Modeling Toolkit, to support working with these languages. However, we are very close to point where the technologies can be applied to real cases. The solution can extend current interfaces and thus does not require that e.g. the OEM should start using these new technologies to obtain the benefits. In the long run, the whole communication could use formal semantic web services languages and for this the existing B2B standards should use these more expressive languages.

VII. CONCLUSIONS AND FUTURE WORK

We presented a concept of solving current integrations problems using standards-based integration. We pointed out shortcomings in the traditional integration technologies and showed how semantic web service technologies are able to overcome existing interoperability related problems. Our solution is still descriptive and needs further evaluation, but the contribution of this paper is to show:

- The role of standards such as RosettaNet or STEP in practical integration efforts. The major benefit of standards is extensibility of integration solution and flexibility to changes in the partners systems. The downside is that standards do not always support adequately the needed interactions and selecting a standard takes time and effort.

- How semantic web technologies enable better validation of incoming messages and can automatically resolve some errors. There are already individual efforts to showcase the use of semantic web ontologies to extend current B2B integrations [10, 13, 14]. Although the technologies might not be yet production use ready, they are moving to that direction.

- Differences between current B2B standards in the automotive supply chain and IT industry in what they cover related to message standardization and secure messaging. Automotive industry is more fragmented in defining the standards where as RosettaNet is more industry-wide. There are also differences in the openness of the standards.

Our future work includes taking this example further to demonstrate a practical showcase on how B2B integration can be accomplished better than currently. We still need to make further evaluation on the suitability of STEP AP 214. Furthermore, more evaluation using semantic web service tools is needed to see what percentage of existing errors we are able to find with our solution.

ACKNOWLEDGEMENT

This material is based upon works supported by the Finnish Funding Agency for Technology and Innovation (Tekes) and the Graduate School for Electronic Business and Software Industry.

REFERENCES

- [1] S. B. Brunnermeier & S. A. Martin. "Interoperability costs in the US automotive supply chain" *Supply Chain Management: An International Journal*, Volume 7(2), 2002, pp. 71-82.
- [2] J. Hendler, T. Berners-Lee & E. Miller. "Integrating Applications on the Semantic Web," *Journal of the Institute of Electrical Engineers of Japan*, Vol 122(10), October, 2002, pp. 676-680.
- [3] A. Hevner, S. March, J. Park & S. Ram. "Design Science in Information Systems Research", *MIS Quarterly*, Vol. 28(1), 2004, pp. 75-105.
- [4] I. Graham, G. Spinardi & R. Williams. "Diversity in the emergence of electronic commerce". *Journal of Information Technology* Volume 11 (2), June 1996, pp. 161 – 172.
- [5] T. Mukhopadhyay and S. Kekre and S. Kalathur. "Business Value of Information Technology: A Study of Electronic Data Interchange", *MIS Quarterly*, Vol 19 (2), June 1995, pp-137-156.
- [6] J-M. Nurmilaakso. "EDI, XML and e-business frameworks", under review.
- [7] D. Roman, U. Keller, H. Lausen, J. de Bruijn, R. Lara, M. Stollberg, A. Polleres, C. Feier, C. Bussler & D. Fensel. "Web Service

- Modeling Ontology". *Applied Ontologies*, Vol. 1(1), 2005, pp. 77 – 106.
- [8] J. de Bruijn, H. Lausen, R. Krummenacher, A. Polleres, L. Predoiu, M. Kifer, & D. Fensel. "The Web Service Modeling Language WSML". <http://www.wsmo.org/TR/d16/d16.1/v0.2/>, March 2005.
- [9] A. Haller, E. Cimpian, A. Mocan, E. Oren & C. Bussler. "WSMX – A Semantic Service-Oriented Architecture". In *Proc. of the 3rd Int. Conf. on Web Services*. 2005. pp. 321 – 328.
- [10] C. Preist, J. E. Cuadrado, S. Battle, S. Williams, & S. Grimm. "Automated Business-to-Business Integration of a Logistics Supply Chain using Semantic Web Services Technology". In *proceedings of 4th International Semantic Web Conference*, 2005.
- [11] P. Kotinurmi, H. Laesvuori, K. Jokinen & T. Soininen. "Integrating Design Document Management Systems using the RosettaNet E-business Framework". In *Proc. of the International Conference on Enterprise Information Systems*, Volume 4, 2004, pp. 502-509.
- [12] N. Anicic, N. Ivezic, A. & Jones. "An Architecture for Semantic Enterprise Application Integration Standards". In *proceedings of the Interop conference*, 2005.
- [13] P. Kotinurmi, T. Vitvar, A. Haller, R. Richardson & A. Boran. "Semantic web services enabled B2B integration", in *Int. Workshop on Data Engineering Issues in E-Commerce and Services*. June 2006.
- [14] F. Tanaka & T. Kishinami. "STEP-based quality diagnosis of shape data of product models for collaborative e-engineering", *Computers in Industry*, Volume 57(3), April 2006, pp. 245-260.