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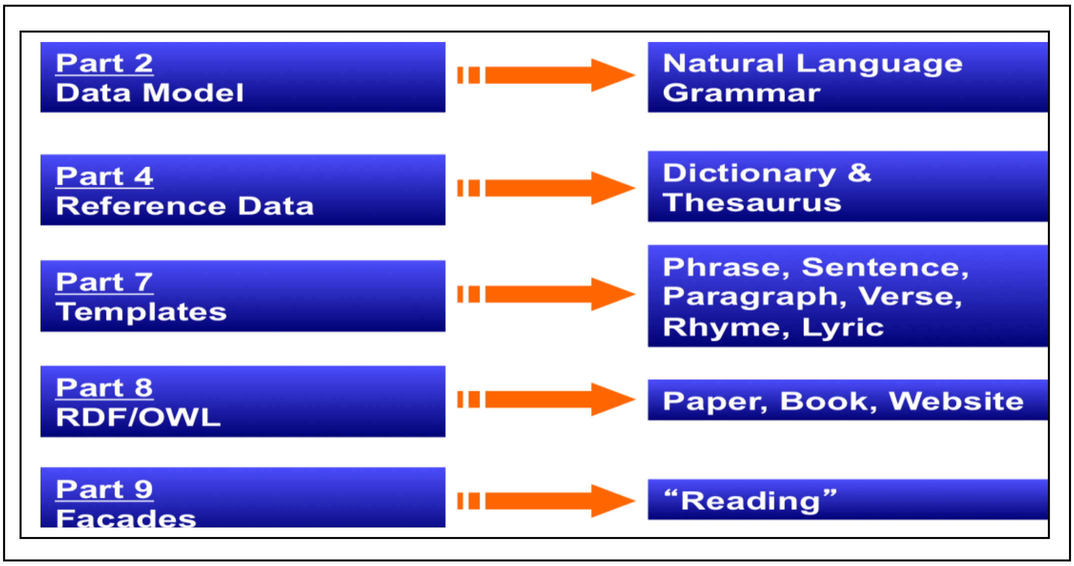

Evaluating interoperability of ISO 15926 implementation:

A case study of IFSWorld Company in the use of data interoperability between computer systems

Master of Science Thesis in Software Engineering and Technology

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Cover:
Different parts of ISO 15926 standard. The standard is like a
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Abstract

Through ongoing global standardization, different specialized organizations are trying to gain stability in the process of plant life-cycle including the stages of design, construction, operation and maintenance. In this regard, exchanging information and knowledge across organizations is of vital importance. ISO 15926 is an international standard for the interoperability and integration of process plant information with other enterprise information. Originally, its information model was established for oil and gas facilities. Implementation of ISO 15926 in organizations depends on available tools supporting the standard. The iRINGTools is a set of open source tools supporting ISO 15926 that is being developed by initiators of the standard.

This report evaluates ISO 15926 and its tools with the purpose of identifying gaps between what the standard and tools offer and what users expect from them. In doing so, IFSWorld Operations Company was selected as a case study for this research. IFSWorld is a software company based in Sweden that develops ERP applications for a major group of customers in the oil and gas industry. Results obtained from this study show that the standard and its open-source tools are still under development and need some increments and modifications to meet user expectations. In particular, the ISO 15926 Reference Data Library (RDL) is not complete yet and at the time, iRINGTools does not support the converting of values, class hierarchy and relationship between data. This report provides users with information about what they can expect from the current state of ISO 15926 standard and its tools. Moreover, this information could be useful for suppliers of the standard to know about users' expectations. The intended audiences of the paper are engineers who work with systems integration and collaboration in architecture and engineering of plants for oil and gas facilities.

Keyword:

Plant lifecycle, Interoperability, Data Interoperability, Process Plant, data sharing, Conceptual modeling, ISO 15926, iRINGTools.

1 Introduction

Plant lifecycle management (PLM) is a strategic approach to create and manage product-information and product-data, in the context of industrial plants, throughout the product's lifecycle [39]. Today, various organizations located in different geographical places, participate and share data during such lifecycles, e.g., design, construction, operation, maintenance and dismantlement [30]. This shows that *interoperability* among systems is a major part of PLM. The IEC TC65/290/DC [40] has defined interoperability as a certain level of compatibility: "The application data, their semantic and application related functionality of each device is so defined that, should any device be replaced with a similar one of different manufacturer, all distributed applications involving the replaced device will continue to operate as before the replacement, but with possible different dynamic responses" (INTEROP documentation, WP1, page 269). According to the work that David Chen and Guy

Doumeingts have done [41], interoperability between two systems can take place on at least three levels: data, resources and processes. The focus of this study is on data interoperability.

However, achieving data interoperability in practice is difficult and expensive. Organizations often have different assumptions about product data. Thus sharing or exchanging data often includes high cost steps of re-keying and reformatting of data. Based on the US National Institute of Standards and Technology (NIST) [18], the US capital facilities industry lost $15.8 billion in 2004 because of inadequate data interoperability between software applications.

An approach to address the data interoperability problem is to establish a *standard generic data model*, such as the ISO 10303, ISO 15926, IFC and AEX standards, for sharing plant data among organizations. Siltanen and Pärnänen [36] established and evaluated data models based on three criteria: business, usability and technical requirements. Based on these criteria, ISO 10303, ISO 15926, IFC and AEX standards were compared. From their comparison, it was concluded that among all standards, ISO 15926 has the possibility to offer a solid base for data integration. Additionally, Braaksma et al., Smith and Shen et al., in their studies have confirmed the advantage of using ISO 15926 for data interoperability [42, 43, and 44]. ISO 15926 was introduced by POSC/Caesar [35] in 2003 to support plant data integration, sharing, exchanging, and hand-over between PLM applications throughout a lifecycle. ISO 15926 includes seven parts in which parts two to four provide a data model and taxonomy and parts four to seven provide techniques and technologies for its implementation.

Currently, POSC Caesar and FIATECH (Fully Integrated and Automated Technology) [14] collaborate to develop ISO 15926 and its tools through a series of projects generally called IDS-ADI (POSC Caesar IDS – Intelligent Data Sets and FIATECH ADI – Advanced Deployment of ISO 15926). Some important projects that have helped to develop and implement ISO 15926 are the Proteus, Camelot, and Avalon projects. The goal of the Camelot project is to implement the full specification of ISO 15926 standard including all its parts. IRINGTools (ISO 15926 Real time Interoperability Network Grid) is a set of free, public domain and open source software tools that were developed during the Camelot project. To establish a framework for data management and interoperability in the industry, FIATECH has published a roadmap [9] and ISO 15926 is a candidate standard for reaching this purpose. In order to develop and implement the standard as the major part of the framework, FIATECH needs to identify the requirements of member companies. Thus, this project was conducted to help FIATECH reach to this goal. In doing so, the IFSWorld Operations Company was selected as a case study for this research.

Problem Definition

As discussed in the previous section, many theoretical studies are available relating to the interoperability of ISO 15926, but when it comes to the actual practical usage of the standard in real cases, few studies have been conducted. To this end, this study focuses on investigating the ISO 15926 standard in the context of the IFSWorld Operations Company (from this time the word IFS will be used instead of IFSWorld) [20].

The IFS is a global software company based in Gothenburg, Sweden that develops ERP applications. The company has about 2000 customers of which a large number are related to the oil and gas industry. IFS uses technologies like web services and brokers to interoperate with other computer systems. But IFS experience has showed that these technologies are not sufficient for interoperability. For example, in an experimental situation, one of IFS's customers faced a data and quantity mismatch while exchanging data between the IFS application and one of the Bentley[1] applications.

Hence, this study has been conducted to resolve the problem of interoperability for IFS with other computer systems. The main goal is to identify the gaps between what the standard and its tools can promise and what users can eventually expect from them.

Purpose

The purpose of this study is to evaluate ISO 15926 and its tools, with respect to data interoperability, in order to identify gaps between what the standard and its tools offer and what users expect from them. The goal is to provide users with information about what can be expected from the current state of ISO 15926 and its tools. Also, this information could be useful to the development process of ISO 15926 and its specific open-source tools.

In order to satisfy the purpose of this study, the author has relied on FIATECH's ISO 15926 tools.

Method

The evaluation method used in this project is called context-based technology evaluation [2]. The method was introduced by the Software Engineering Institute in 2005 [20] to determine the fitness of a technology within a specific context. This method involved the following steps: firstly, identifying company expectations on the evaluated technology and constraints that must be considered during the evaluation, (expectations may be further subdivided into expectations involving functionality and those involved quality attributes, such as performance, usability, ease of development, or maintainability); secondly developing model problems (model problems simulate potential problems in an organization and demonstrate whether the evaluated technology could solve those problems or not). And finally, analyzing model problems results against technology usage context.

Grace A. Lewis defined model problems as prototypes that allow conducting hands-on experimentation with the technologies before they are inserted into the organization [2]. Our steps for developing model problems were as follows: 1. we developed hypotheses, 2. we developed criteria, 3. we designed model solution, 4. we implemented and evaluated the model solution against our criteria. Hypotheses were claims about the technology and derived from expectations. Criteria were used to accept or reject a model solution for a hypothesis.

Some of the identified expectations of the technology from the context of IFS Company were data interoperability, performance and data accuracy. Results showed that the hypothesis of data interoperability was held by iRINGTools. There are different *Application Programming Interfaces (APIs)*[2] for iRINGTools that could be used to work with diverse applications.

[1] Bentley is a software company that produces solutions for the design, construction and operation of infrastructure. Their software solutions are used to design, engineer, build and operate large constructed assets such as roadways, railways, bridges, industrial and power plants and utility networks.

[2] API is a set of codes and specifications that let software programs interact with each other. It serves as an interface between software programs to exchange information. Since understanding the code of an open-source software is very time consuming, developing API for a free software provides a quick and easy way to work with such applications.

Although, iRINGTools crashed when using large amounts of IFS's data in the beginning, applying some modifications to iRINGTools code, enabled performance to reach a reasonable level. Furthermore, since iRINGTools is open-source, companies could use different strategies to customize it to work with their data, such as data caching. Thus iRINGTools met user expectation.

In contrast to the data interoperability and performance hypotheses evaluations, accuracy evaluation of iRINGTools was relatively difficult because the Reference Data Library (RDL) of ISO 15926 was not complete and it was necessary to get familiar with the available entities in the ISO 15926 data model. This was taken into consideration when describing the experiments about evaluating the accuracy hypothesis. As a result, it was concluded that at the moment it was not possible to get correct data automatically by using ISO 15926 and iRINGTools.

Outline

This thesis is organized as follows. Chapter two describes the interoperability of the ISO 15926 standard based on the *Levels of Conceptual Interoperability Model (LCIM)*. Chapter three gives a summary of the applied method, chapter four brings details of our experiments and chapter five presents our results from the evaluation. The related works of this paper are presented in chapter six, followed by chapter seven which describes the most important outcomes of the study. Finally, future work and conclusion are given in chapter eight and chapter nine.

2 Theoretical frameworks

This chapter explains the theoretical background of the ISO 15926 standard and iRINGTools as described in the existing research literature. Since the goal of this study was to investigate the data interoperability between systems by using the ISO 15926 standard, a part of the theoretical studies of this research has been done on the data interpretability concept and its different quality levels. The ISO 15926 standard and iRINGTools are explained in sections 2.1 and 2.2, followed by sections 2.3 and 2.4 which describe data interpretability and conceptual modeling.

2.1 ISO 15926 standard

ISO 15926 standard consists of seven parts; the main parts of the standard are part two, four and seven. Descriptions of these parts will be presented below while the other parts of the standard are described in Appendix A.

Part two of the standard resembles the basic rules of a grammar in a natural language. It defines rules and constraints on using ISO 15926 for data interoperability between computer systems. In essence, it is an ontology defining basic axioms such as class and individual at the top level, and subtypes of these axiomatic concepts such as physical object and connections at a lower level [33].

Part four of the standard contains an initial set of reference data - known as Reference Data Library (RDL) - to be used with part two of the ISO 15926. When two computer systems use the same terminology (i.e., use the same RDL) and rules (i.e., use the same data models provided by part two), they can communicate easily. These two parts of the standard define how the data must be interpreted; the other parts of the standard define the implementation methods used to deliver the data.

Part seven defines implementation methods for the integration of distributed systems. It represents units of information called templates. Templates are like phrases in a natural language phrase-book which provide a way to use ISO 15926 more efficiently. Actually, they are preconfigured definitions that point to objects in part two.

To deploy and implement running interoperable applications, based on ISO 15926, the standard applies two technologies from the Semantic Web, Web Ontology Language (OWL) and Resource Description Framework (RDF). OWL is a language for creating ontologies and RDF is a way to store information in the form of ontologies to make it readable by machines. The ISO 15926 community develops required tools for applied technologies and methods. These tools are offered under the general name iRINGTools which is described in the following section.

2.2 IRINGTools

POSC Caesar Association (PCA) [13] and FIATECH [14] member companies collaborate together to accelerate the deployment of ISO 15926 and activities around that. They propose the ISO 15926 Real-time Interoperability Network Grids (iRING) concept as a set of data interoperability and integration protocols, and RDL which is an internal part of the standard. In fact, iRING is a commercial label for ISO 15926, which provided protocols and tools.

The reason for this collaboration was the increasing demands for ISO 15926-based interoperability [32]. Therefore, the iRING community decided to provide ISO 15926 or iRING interfaces ready for commercial software products. For this purpose, iRINGTools Interfacing Project (IIP) has been established. By this joint effort, the cost and time for implementing the interoperability solutions in organizations can be decreased. The goal of the IIP project is to deliver a set of free, public domain and open source software tools that are called iRINGTools [16].

IRINGTools is a web based technology suite. It is developed using C# and Java programming languages. It provides a medium to define and exchange real time information through web based services. Companies can use the iRINGTools to exchange information both internally and externally by mapping their own data structures to the ISO 15926 ontology and also, from the ISO 15926 ontology to their own data structures.

To transfer data from one software application to another software application, based on the ISO 15926 standard, first the source software application must convert data into the ISO 15926 ontology by *iRINGTools adapter*. On the other side, the target software application needs to apply the iRINGTools adapter to convert the ISO 15926 ontology into its own data structure. This transmission is handled by *iRINGTools web services*. Figure 1 illustrates the main components of iRINGTools.

Also, iRINGTools provides companies with the components which facilitate browsing and publishing their own data classes to the Reference Data Library (RDL) to be used for their private data interoperability purposes. Other components included in the iRINGTools suite are templates for modeling relationships, facades for exchanging information and an editor which can be used to map a company’s legacy data to the ISO 15926 ontology. The key components of iRINGTools that facilitate data transformation are the following: RDS/WIP, RDS/WIP browsers and editors, Sandbox/es and iRINGTools Mapping Editor.

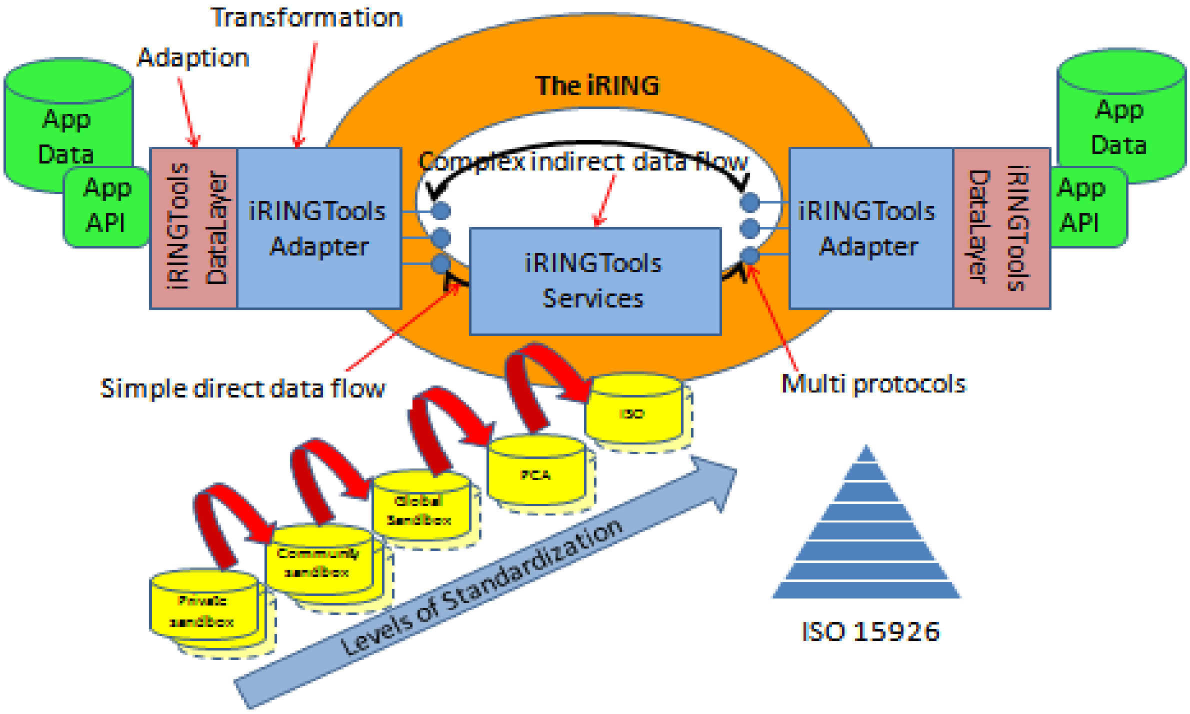

Figure 1, iRINGTools-big picture.

Reference Data System/Work in Progress (RDS/WIP) [45] is used to publish definitions in ISO 15926. It is a library based on OWL/RDF and uses SPARQL for querying the data. It is extensible and is therefore referred to as Work In Progress (WIP) (IDS-ADI 2011). The RDS/WIP Editor enables user to browse ISO 15926's RDL and add new classes through the sandboxes. There is a group which guide users of iRINGTools to develop ISO 15926 protocols and software tools, called iRINGUserGroup.

In addition, the IRINGUserGroup hosts the IIP project and its goal is to deliver a set of iRINGTools Data Layer modules and initial iRINGTools mapping files that provides ISO 15926 interfaces ready for key commercial software products. They are delivered as different APIs allowing access to different types of data warehouses, such as Smart Plant P&ID, 3D models, etc.

The IIP project consists of three sub groups: Requirements, Software Development, and User Acceptance Testing. The Requirements group defines the scope of API properties required to access to the information on each API. Another task of this group is to identify how Reference Data Library (RDL) items correspond to API properties, for example one property of a pipe line in IFS is Material which corresponds to the PipingMaterialsClassAll in the RDL. The Software Development team develops customized iRINGTools Data layers specified to the requirements of each API. The User Acceptance Testing sub team provides iRINGTools mapping files for each API Data Layer module. Also, to eliminate different *interoperations* of ISO 15926 standard, iRINGUserGroup conducts various meetings to get users' feedback along with sub team meetings.

2.3 Data Interoperability

According to ISO/IEC 2382-01, interoperability is defined as "The capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units" [37]. This definition is ambiguous because the user of a system could be another system. In software systems, interoperability is defined as the capability of different programs to exchange data by using a common set of exchange formats. Interoperability could affect a company's economy negatively, for instance, if the products of an organization are not interoperable (due to patents or trade secrets), the result may be market failure or monopoly.

There are different levels of interoperability between two systems ranging from no interoperability to full interoperability. Page et al. [22] have differentiated between the technical layer for integratability, the implementation layer for interoperability and the modeling layer for composability. Later research at the Virginia Modeling Analysis and Simulation Center produced the Levels of Conceptual Interoperability Model (LCIM) [22]. More recently, after gradual improvements in the LCIM, the current LCIM model was introduced [23], as illustrated in figure 2. The model has six levels. The first level of the model is called Technical Interoperability which is related to the hardware communication and protocol layer. Technical interoperability is necessary but not sufficient for interoperability between systems. Different systems need to have the same view of captured concepts in data models. An overview of the LCIM model and its other levels can be found in Appendix B.

The technology that can enable data interoperability among computer systems is data modeling. Many attempts have been made to use modeling and simulation in order to capture systems' requirements and assumptions for interoperability. However it has been observed that modeling became more and more a backbone of operational research to cope with very complex and dynamic environments [4].

A data model within a specific domain should include the definition of all objects (For example, line, valve and etc.) in the domain as well as constraints and relationships between objects. Data models can be created using data modeling languages. ISO 15926 uses EXPRESS to define its data model, but currently XML is used in adaption with Web-based applications.

Ontologies are a way of capturing concepts, relationships and rules of data in an organization. A standard can enable a number of systems to interoperate with each other based-on federating each system's own ontological representation. At the moment, many standards deal with technical interoperability, like IEEE 1278 and IEEE 1516. But, ISO 15926 was introduced to provide standardization at the conceptual modeling level and to ensure proper interoperability between computer systems. The next chapter describes conceptual modeling of the proposed LCIM.

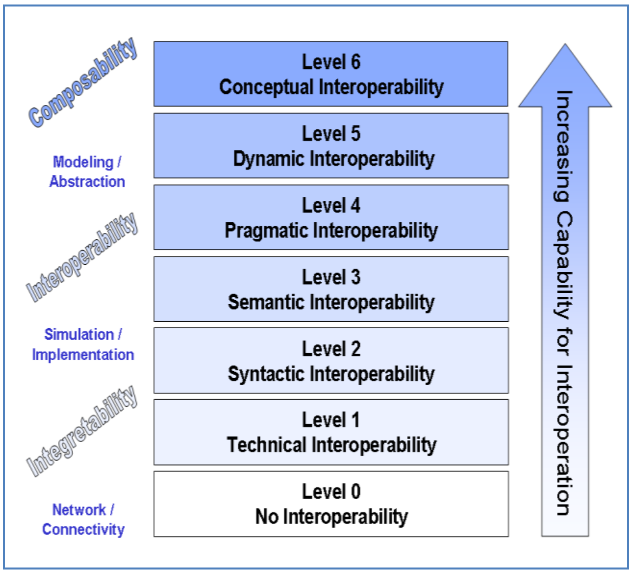

Figure 2: Levels of Conceptual Interoperability Model [22]

2.4 Conceptual Modeling

Conceptual models are used to represent concepts (entities) and relationships between them in a specific domain. Conceptual models should not be confused with data modeling, physical modeling or logical modeling. Data modeling is a technique for defining business requirements for a database. It is also called database modeling since a data model is eventually implemented in a database [5]. The logical model describes the data in details without regard to how they will be physically implemented in the database. And the physical data model represents how the model will be executed in a particular Database Management System. But a conceptual model shows how different systems interact with each other.

A series of standard methods are required to support the creation of various conceptual models. In the process of creating one conceptual model, conceptual data domains and the required information for exchanging data must be gathered. The result of this activity is an ontology that can satisfy the requirements of the information exchange between computer systems. There has been a huge effort to represent ISO 15926 ontologies by using OWL including: [25, 26, and 27]. The ISO 15926 standard enables software applications to interoperate based on their own ontologies by federating ontologies of different software applications. In contrast to other standards for interoperability and composability which focus on exchanging a common data model, ISO 15926 focuses on conceptual interoperability. Based on [4, 7] the ISO 15926 standard provides the highest level of interoperability in LCIM. Through the use of ISO 15926 Entity Types and Reference Data, Matthew West demonstrates the effectiveness of an ontological approach to information systems design [6]. The work includes a case study of development ontologies for Shell Company’s Data Model. The details of ISO 15926 information modeling could be found in [8]. Figure 3 shows an example of ISO 15926 ontology.

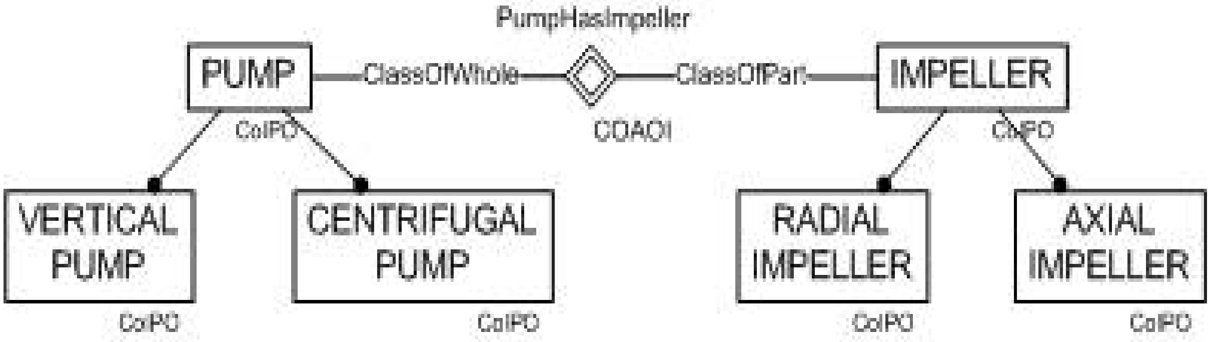

Figure 2: ISO 15926 ontology

3. Method

A context-based technology evaluation [2] was deployed to investigate the implementation of ISO 15926 for IFS applications. In this methodology, to determine a fit between systems and technology, it is necessary to evaluate technologies within the contexts in which they will be used. The scope of the evaluation is only concerned with technical issues not business, legal and other aspects. The process is outlined in Figure 4.

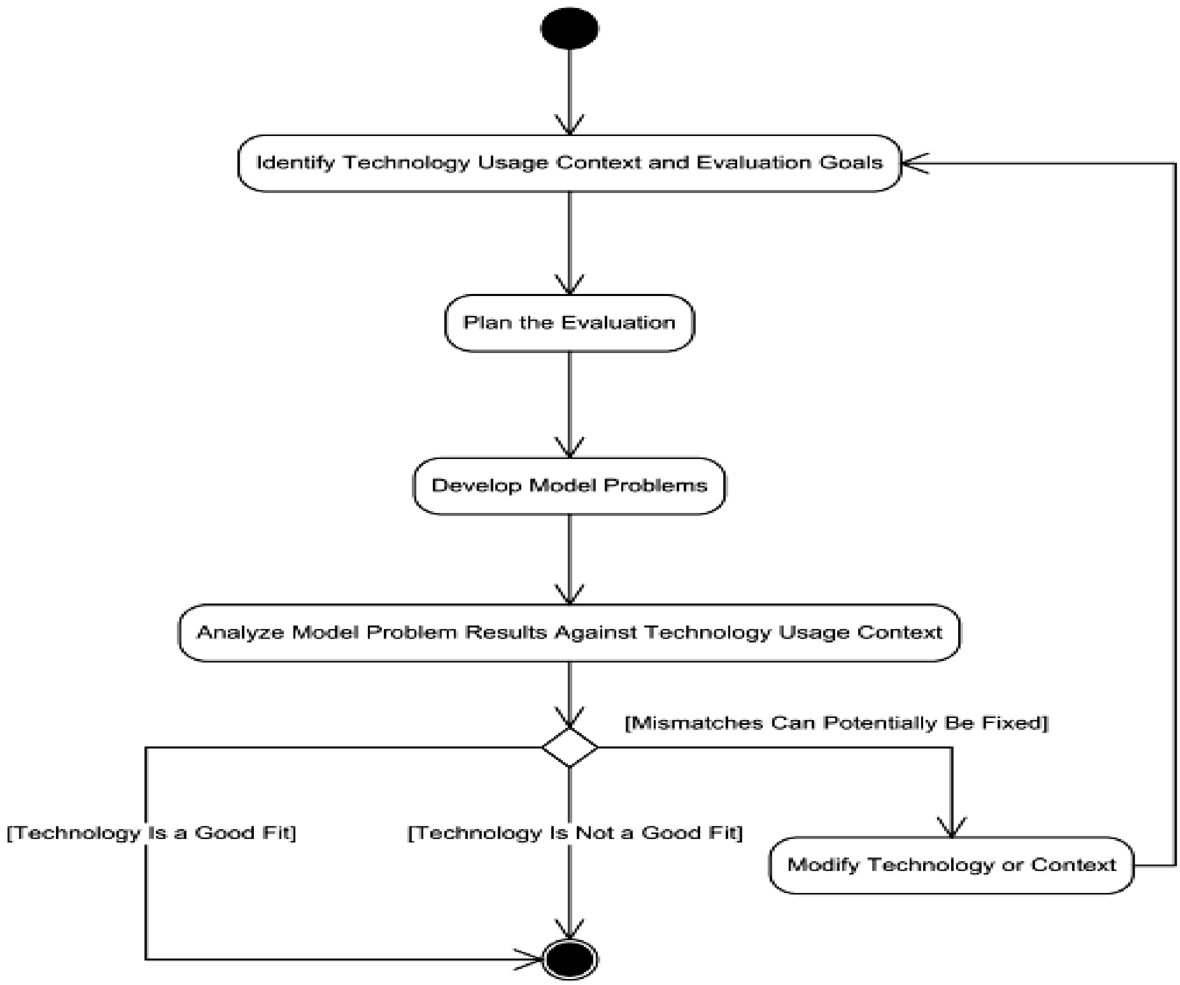

Figure 4: Context-Based Technology Evaluation [2]

A part of this method is the development of model problems. This can be used for the evaluation of web services, database systems or architectural frameworks and development tools.

3.1 Evaluation context

This process involves (1) identifying technology usage context and evaluation goals, (2) planning the evaluation, (3) developing model problems and (4) analyzing model problem results against technology usage context.

The context for evaluation is IFS Asset Design. Their product Applications includes a number of services that send or receive information. Some are generic, such as the reporting framework or replication functionality. Other services, such as order confirmations and invoices, belong to specific business components. With IFS Applications, all services send or receive information using XML natively. This means that IFS Applications are ideally suited to integration with other applications that also operate with XML and web services technologies. Besides using web services for integration, different formats (for example another XML format or a delimited file) and protocols are provided using an integration broker module. Despite this apparent interoperability, problems of interoperating with other applications were still observed.

3.2 Goals of the Evaluation

The goal of the evaluation is to determine how the implementation of ISO 15926 affects following aspects:

- Correctness of exchanged data between two systems with different data models.
- Ability to integrate IFS's Asset Information Integration Manager (AIIM) with required technologies for implementation of the ISO 15926 standard.
- Performance of the tools.

3.3 Scope of the evaluation

The evaluation has been restricted to those types of information systems that are used in the oil and gas industry. Other aspects of exchanging data in information systems excluded in the goals of the evaluation are beyond the scope of this study.

3.4 Expectation for the technology

The expectation of the project is to facilitate IFS Asset Design to interoperate with external systems according to the ISO 15926 standard.

3.5 Constraints

Since this is a preliminary study, there is not a budget for the purchase of new software applications. All technologies and software should be free, open source or already licensed for the organization.

3.6 Plan the evaluation

In order to plan the study, the study is divided into tasks according to the context-based technology evaluation as follows:

3.6.1 Evaluation Team

For the evaluation team, a member with a background in Information Technology (IT) and a systems analyst from IFS Asset Design were identified. These members were the main actors in the project.

The IT professional was expected to contribute full time for about 5 months. The systems analyst supervised on the project and provided necessary resources for the study.

3.6.2 Stakeholders Identification

The stakeholder identification was conducted to identify stakeholders and their responsibilities. Their inputs to the evaluation were important because the technology should be investigated based on their expectations and constraints. Table1 outlines different stakeholders and their responsibilities.

3.6.1 Evaluation Team

For the evaluation team, a member with a background in Information Technology (IT) and a systems analyst from IFS Asset Design were identified. These members were the main actors in the project.

The IT professional was expected to contribute full time for about 5 months. The systems analyst supervised on the project and provided necessary resources for the study.

3.6.2 Stakeholders Identification

The stakeholder identification was conducted to identify stakeholders and their responsibilities. Their inputs to the evaluation were important because the technology should be investigated based on their expectations and constraints. Table1 outlines different stakeholders and their responsibilities.

Responsibility / Stakeholder	Business Concerns	Technical Requirements	Technology Requirements	Sponsorship	Negotiation
Product Manager	✓			✓	✓
Business Solution Architect	✓		✓	✓	✓
Current system developers		✓			
Framework team			✓		

Table 1, Stakeholders and their responsibilities in the evaluation.

3.6 Approach

Because of the organization's constraints of using open-source software, iRINGTools was selected as a tool for the implementation of ISO 15926 in IFS Asset Design. Several Internet searches were conducted to understand the standard, its principles and iRINGTools. Also, different meetings were held with iRINGTools vendors. Since tools and protocols were still under development, some inputs were delivered to iRING project in order to simplify its future integration with IFS applications. Because of the organization's limitations, some modifications were done in iRINGTools assumptions for installation, such as, the supposed operating system for iRINGTools (Windows Server 2003 SP2) was changed to Windows 7; this effected other deployment configurations for the installation of iRINGTools on IFS's computer systems. To install iRINGTools on Windows 7, Microsoft WebMatrix was used instead of Internet Information Services (IIS).

3.7 Model Problem Setup

Model problems were created as a technique for evaluating commercial components. Development of model problems involved the following steps: developing hypotheses, developing criteria, designing model solution, and implementation and evaluation of model solution against criteria. The first step in the technique was to define the hypotheses. Hypotheses were claims about the technologies that were to be sustained or refused. In fact, they were functional requirements and quality attributes that were expected to be held by the technologies. For iRINGTools, the following initial hypotheses were selected from ISO/IEC 9126-1 quality model [10]:

H1. IRINGTools allows composition of systems and can provide data interoperability between two applications with different data models.

H2. Exchanged data using IRINGTools is accurate.

H3. The performance of iRINGTools is reasonable while accessing the data in database.

Criteria were used to determine if a hypothesis was sustained or refuted. Each hypothesis had one or more criteria. They were stated as clearly measurable statements of capability. For the above hypotheses, the defined criteria were listed in Table2.

Table 2: Hypotheses and their Criteria for the iRINGTools investigation

Hypothesis	Criteria
IRINGTools allows composition of systems and could provide data interoperability between two applications with different data models.	• IRINGTools can be integrated into AIIM. • IRINGTools can provide data interoperability between two systems.
Exchanged data using IRINGTools were accurate.	• Exchanged data did not changed while transferring from source to the target. • There was a match between data attributes at source and target.
The performance of iRINGTools was reasonable while accessing the data in database.	• IRINGTools could fetch all objects in database without crashing. • There were additional functionalities in iRINGTools that could help to increase the performance of the software application while working with huge amount of data.

3.8 Design and Implement Model Solutions

A model solution is a technique by which information is collected to sustain or refute a hypothesis. Building a model solution involved the following steps: defining the scenario, defining technical solutions that satisfy the scenario and the implementation of a model solution [2]. A model solution involved the simplest set of software components that could sustain or refute a hypothesis as measured by the associated criteria.

3.8.1 Hypothesis 1:

IRINGTools allowed composition of systems and could provide data interoperability between two applications with different data models.

Scenario, IFS wanted to exchange data between the AIIM and a Bentley application. Bentley AutoPLANT component data and IFS data sets were separate entities. A user should be able to integrate iRINGTools to AIIM and do data exchange between the two systems by using iRINGTools.

Model Solution, AIIM could support data inputs such as Excel files. IRINGTools could interoperate with AIIM by using Microsoft SQL and Microsoft Excel. This allowed the usage of iRINGTools to import data from the Bentley application into the AIIM. Due to business limitations, data was not sent from AIIM to Bentley. However in another scenario using iRINGTools, data was pushed from the IFS database to a test façade. By having façade URL, Bentley can use the former scenario to get data. Data was pulled from Bentley Façade [11] to AIIM as follows:

- By using iRINGTools data was pulled from Bentley Façade to one MSSQL table. The columns of this table are same as object properties in AIIM.
- By using Data tab in Microsoft Excel, data was retrieved from a MSSQL table to one sheet in Microsoft Excel and AIIM could read this Excel file.

The model solution for this hypothesis is illustrated in figure 5.

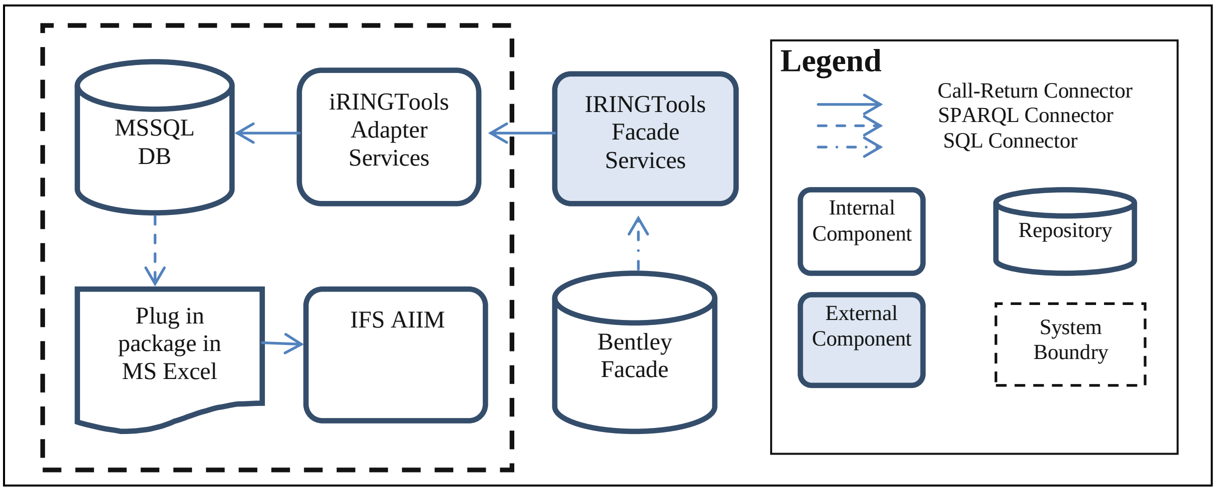

Figure 5: Model Solution for Hypothesis 1.

3.8.2 Hypothesis 2:

Pulled data via iRINGTools was accurate as it was expected to match to destination's data model.

Scenario, a person changed one record in a database so that the adjustment can be reflected in another related database. By using iRINGTools, this exchange can be done between two systems with the same and different data models.

Model Solution, two tables (Table 1 and Table 2) were created in two different databases in MSSQL. IRINGTools Adapter was used to map their data models to the ISO 15926 data model. The IRINGTools façade exchange utility was used to pull data from Table 1 to Table

2. The value of one record in Table 1 modified after pulling data to Table 2, the desired value was seen in Table 2. Figure 6 illustrated the solution model for this hypothesis.

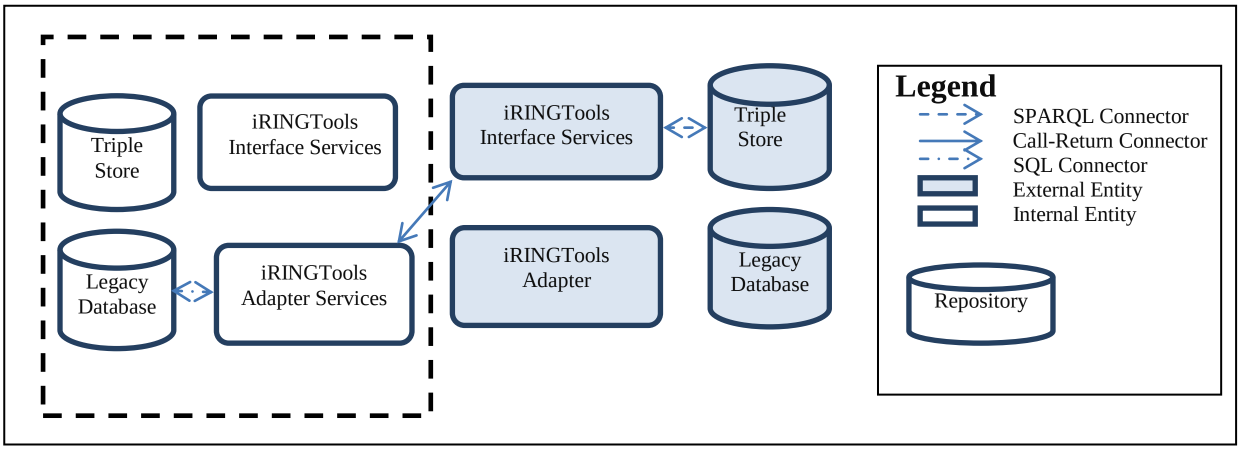

Figure 6: Model Solution for Hypothesis 2 (This Flow Chart only shows exchanging of data between two systems regardless of internal communications).

Hypothesis 3:

The performance of iRINGTools was reasonable while accessing the data in the database.

Scenario, a person wanted to use the iRINGTools Application Editor to access an object in IFS database. This object is used later for making a database dictionary. She/he enters the credentials of database. After making a database dictionary and mapping the legacy data model to the ISO 15926 data model, the user exchanges data between the two systems by using iRINGTools Exchange utility.

Model Solution, in the AIIM there was a possibility to define different users with various permissions to access data in the IFS database. To test whether iRINGTools can fetch all objects in database without crashing, we defined a user with full access to database. Originally, iRINGTools crashed when fetching all objects from the IFS database. We came up with two solutions for this model solution. The first solution was to change Oracle queries in iRINGTools NHibernate code to fetch some objects. The result was successful and iRINGTools could fetch the desired objects from the Oracle Database in a reasonable time. The second solution was to define a user in the IFS application that had access to some objects in the database. Fortunately, there is an option in iRINGTools Application Editor to specify credentials for a specific user; however, the problem was reported to the iRINGTools development team, as well. At the time they decided to add data caching and functionality to iRINGTools in order to filter specific amount of data.

4 Experiments

In this step, the model solutions were evaluated against criteria to see whether the hypotheses were accurate. The results of evaluations are presented in later sections. They cover the experiments during the implementation of model solutions.

4.1 Experiments-Hypothesis H1:

This experiment was introduced in order to investigate how AIIM integrates with iRINGTools and for that, different model solutions were selected. They were including web services, available APIs on IFS application for accessing to the business logic, and integration of iRINGTools with AIIM using intercessor tools without any modifications in codes of both applications. Integration based on Web services and XML was investigated but it was found that these functionalities were still under development in iRINGTools. Also, the usage of IFS application's APIs required code merging and some programming that was beyond the scope of this study. The important thing about this hypothesis was interoperability between AIIM and iRINGTools; therefore, a solution was developed without any modifications in the applications' codes. AIIM could accept inputs as Excel file and iRINGTools could pull data to an intermediate database, such as Microsoft SQL. Therefore, Microsoft SQL and Excel played an intercessor role to make interoperability between iRINGTools and AIIM.

4.2 Experiments-Hypothesis H2

The goal of this experiment was to examine the accuracy of iRINGTools in data exchange. To develop a model solution for this hypothesis, it was first necessary to install iRINGTools and understand its user guide. Due to the organization's limitations, iRINGTools needed to be installed on Windows XP or 7. It could not be installed on Windows XP because Windows XP's IIS (IIS 5.1) did not support Silverlight 4 applications and iRINGTools were developed on Silverlight 4. Therefore, another option was Windows 7 and it required Microsoft WebMatrix to host iRINGTools on the Internet. This solution was easier than applying IIS.

Different tests have been conducted to understand the work flow of iRINGTools. The iRINGTools user guide [27] is a primary document for learning iRINGTools however it is not enough to understand iRINGTools in details.

To test data exchange of iRINGTools, a project and application was defined in its Application Editor. Figure 7 shows a snapshot of the tool[3].

[3]This environment has been added to the iRINGTools Adapter Manager in the last version of the tools but because of the time limitation, the investigation of the new environment was impossible however the core concepts are still same.

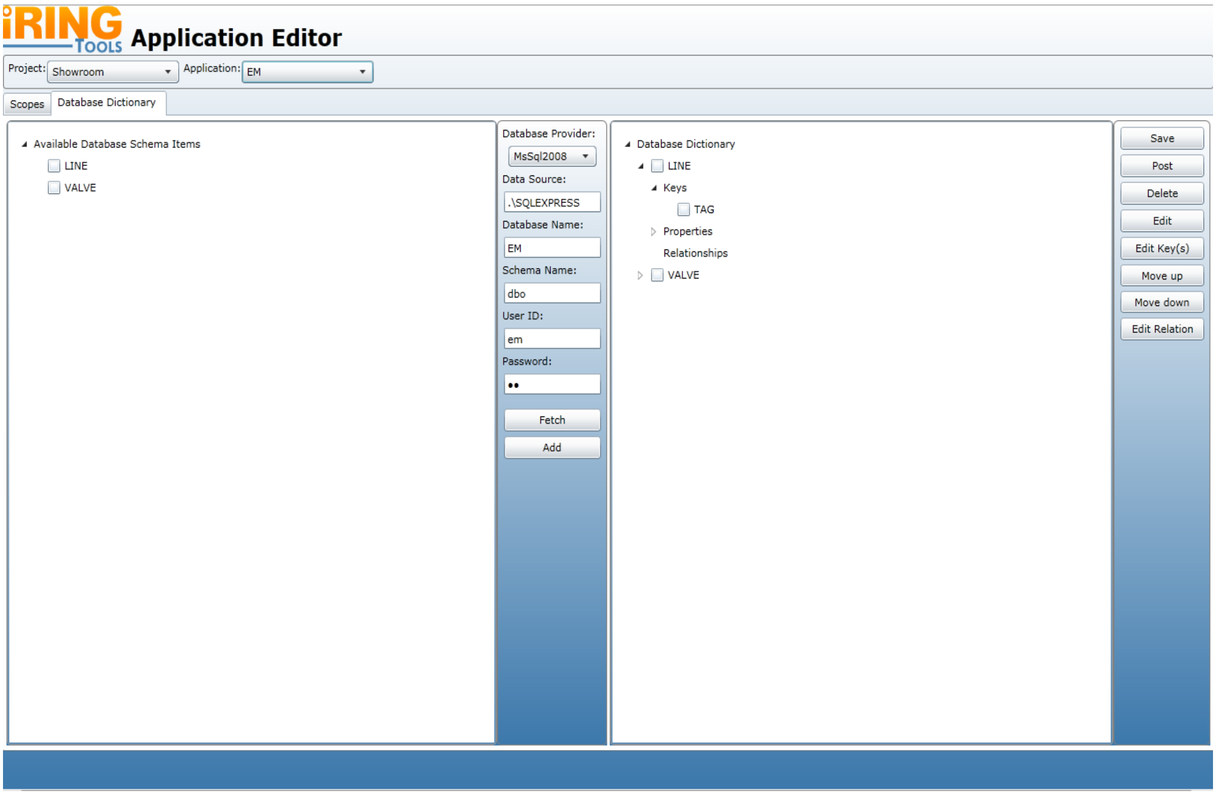

Figure 7: iRINGTools' Application Editor.

The goal of the Application Editor was to produce a data dictionary using the NHibernate data layer. In the current version of iRINGTools, Data dictionary was a XML file that provides metadata of the selected object to facilitate the Data Layer with the ability to interact with objects through the interfaces. The next step was mapping which was performed in the Mapping Editor of iRINGTools. Mapping is a technique which projects data of each sender and receiver to a common set of reference data, here called ISO 15926 RDL. Through use of ISO 15926 mapping, the complexity and redundancy of "point-to-point" mappings were eliminated. When one data endpoint changed, only mapping for that point was updated and it did not need to make changes in other sides. Mapping could be useful in many respects, since it removed popular "point-to-point" data exchanges and consequently the number of endpoints that needed mapping decreased. Also it helps with "loose coupling" by decreasing the dependency between computer systems; hence the impact of change in one system will be reduced on the coupled system.

Mapping required initial knowledge about information modeling using ISO 15926. Modeling was not an IT function but a business function. The iRINGTools modeling group in [8] provided a comprehensive discussion about ISO 15926 modeling. However, for creating this model solution, only some simple models were used to test the accuracy of iRINGTools in data interoperability. It is worth mentioning that one can learn information modeling mainly through practicing not just through reading. For this purpose, iRINGToolsUserGroup held modeling meetings which could be useful for people who would like to know about ISO 15926 modeling. In regards to mapping, it was important to learn about how to use templates. With the "iRINGToolsReferenceData Editor", each company could define its own templates and classes. The complete current list of templates could be found in [28]. As an example, figure 8 shows a diagram for "TAG NAME" property of a pump.

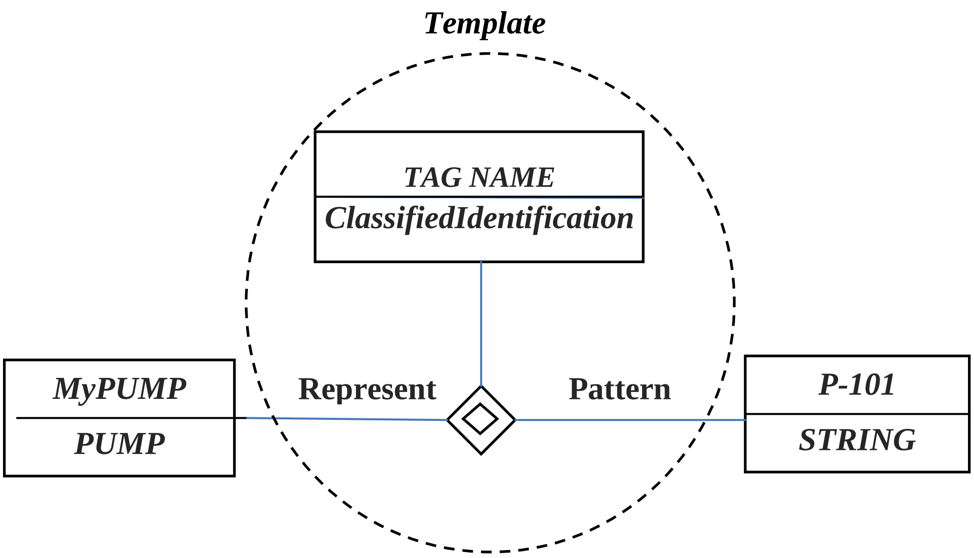

Figure 8: A template to specify the *TAG NAME* of a PUMP.

To map TAG NAME of a pump into ISO 15926 RDL, almost the same diagram must be created in the Mapping Editor of iRINGTools. In iRINGTools, the set of all these templates and classes for an object is called *Graph*. Table 3 shows descriptions of test cases that have been developed to examine this hypothesis against criteria.

Table 3: developed test cases for testing of iRINGTools against criteria of hypothesis 2.

Test Case	Description
1.	• Create 2 tables with exactly same properties. • Use iRINGTools to send values of two columns from table 1 to table 2. • iRINGTools must send data correctly.
2.	• Create 2 tables with different columns; this difference must be in the name of properties and the number of columns. • Use iRINGTools to send values of two columns from table 1 to table 2. • New data in table 2 must be correct and follow destination constraints.
3.	• Create two tables and fill them with same values (values of table 1 must be same in table 2.). • Change the value of one non-key column of a record in table 1. • Pull data from table 1 to table 2, the value of exactly same cell in table 2 must be updated with new the value.

4.3 Experiments-Hypothesis H3

The goal of this experiment was to examine the performance of iRINGTools. Initially, a user was defined in Application Editor. This user has full access to all IFS's objects including tables, views and triggers. There were about 38000 objects in the IFS database. On different computer systems, different results were seen. While in a system with 2 GB RAM and a 2.33 GHz processor, iRINGTools crashed, in another system with 4 GB RAM and a 2.53 GHz processor, it took about 40 minutes to fetch all the objects from the database. As mentioned previously, the Application Editor was used to make a Data Dictionary. This module fetched all objects for a specific user from the database and then a person could make a Data Dictionary for its desired object(s). The problem was reported to iRINGToolsUserGroup and a solution was to store mostly used tables in the cache memory. But a temporary solution for IFS was to define users with limited access to IFS objects. Also, another solution tested was to change data queries in the NHibernateProvider library of iRINGTools to filter some specific objects.

5 Analysis

This section analyzes model solutions against the criteria in order to determine whether hypotheses were met. The results are provided in the following sections.

Analysis of experiment H1

A prototype was made to integrate the AIIM with iRINGTools to see how data interoperability between the IFS's application and iRINGTools could inform further studies on ISO 15926 and iRINGTools. There were different options in the iRINGTools which could provide data interoperability between software applications. The iRINGTools provided Web Services that could be used for integration with other software applications which were implemented Web Services as well. Also, iRINGTools could project data in different formats such as, XML, RDF, etc. In other words, the iRINGTools Adapter could produce data in different levels of the ISO standard. It could produce part seven XML, part seven Data Transfer Object (DTO), part eight RDF/OWL and part nine Triple stores. Each company could use these different types of data structure based on their requirements. Generally, it was observed that this hypothesis held true when using iRINGTools.

Analysis of experiment H2

The accuracy of iRINGTools in sharing of data was related to ISO 15926 data modeling. It was necessary to become familiar with the existing content of the RDL in order to use classes and templates in the suitable situations. Otherwise, it was possible to get wrong data. The current version of iRINGTools did not support inheritance but it was in development. Also, it is worth mentioning that it was better to delete a used graph in the façade before reusing it again, because if a graph had values and was published into the façade, the values in the graph could not be updated in new ones; in other words, they are immutable. By considering all these factors, it became apparent that iRINGTools could pass all mentioned test cases successfully. Therefore, iRINGTools could exchange data correctly, if the mentioned requirements were satisfied.

Analysis of experiment H3

It has been seen that the iRINGTools development team tries to apply best practices for increasing performance of iRINGTools. So with some changes such as optimizing data queries, data filtering and caching, the performance of iRINGTools could be improved. Therefore, even though in the beginning iRINGTools did not meet this hypothesis, with some modifications in its code, the hypothesis held.

6 Related works

The related works of this paper were associated with several areas, such as Ontology based approaches and standards for interoperability and available tools that facilitate this kind of interoperability. Most of the similar works have evaluated the ISO 15926 standard as it would be completed. In addition, almost no studies have been conducted to investigate its available tools. Therefore, this chapter provides the readers with information about related works on evaluation of the final version of ISO 15926.

Tolk [3, 4] presented the Levels of Conceptual interoperability Model (LCIM) to bridge the conceptual and the technical design for implementation, integration and federation. The model could be used as a framework to determine whether meaningful interoperability between systems is possible or not. Based on this model, in order to reach to the higher level of interoperability between computer systems, the definition of a common ontology and federation of shared data elements was not sufficient for conceptual interoperability. The conceptual models describe which parts of the real world are modeled under which constraints and sometimes even which parts are not modeled. In other words, the conceptual models must examine the *Semantic Relations* between participating entities. The ISO 15926 standard provides Semantic Relations between objects. In this regard, it can be used to create conceptual models for oil and gas facilities.

Matthew West [6] showed that ontologies are practically useful for business information systems. He has demonstrated an ontological framework for development of business information systems with the focus on the conceptual data modeling. In his work, he has used the ISO 15926 data model and its reference data to make an ontology for *Shell*'s information system.

Tore Christiansen [34] used Protégé[4] to implement ISO 15926 Core Data Model into the OWL. Protégé is a free and open source ontology editor that supports ontology's modeling and visualization in various representation formats such as, RDF(s), OWL and XML Schema [38]. The purpose of the project was to verify that there is a way to represent information about real world artifacts and activities using ISO 15926 RDL.

7 Discussions

Our investigation shows that both ISO 15926 and iRINGTools are still in the development phase and they still need further work to be used as a standard for data interoperability in process plant's lifecycle. Today, the reliable sources of ISO 15926 reference data exist mostly at the "data model" level (part two of ISO 15926, including 201 concepts) and are a part of the core concepts that often appear in the engineering field. But at the "template" level (part

[4] http://protege.stanford.edu/

seven of ISO 15926), the amount of approved templates by the professional community is small. Mostly, they are being developed for specific projects and are not made publicly available [30]. But right now, if some companies agree on common templates, iRINGTools could be used for data interoperability between their systems.

Today, the Adapter and Mapping Editor tools in iRINGTools can be applied to project original data from a system, considered as a sender, to an ISO 15926 data structure and further to convert data in the ISO 15926 format to a receiver data structure. The role of the adapter is to transfer the data structure of a warehouse to the mapping editor. Adapters are unique for each data warehouse type. For example, SmartPlant requires one adapter, and 3D models of CAD systems need another. At the moment, all of these adapters are included in the plan of the iRING project to be developed. The Current version of iRINGTools has a “universal” adapter, meaning it operates on data of relational databases. Therefore, other types of data structures must be simplified to relational databases.

It could be argued that iRINGTools lacks the ability to share data in different units of measurement among information systems. There is no support in iRINGTools for converting values in one system to another system. For example, if a system uses Celsius as its unit of measurement for temperature, iRINGTools could not convert that value into the Fahrenheit for use in another system.

8 Future works

One subject that remains for further investigation is the “Transformation Framework” of iRINGTools. The Adapter Library of iRINGTools includes files to project data into various formats such as, RDF, HTML, XML and etc. This possibility gives a better ability for systems in order to perform data integration with other systems. "Transformation Framework" was not investigated in this thesis since it was added to iRINGTools at the end of our evaluation’s time plan.

9 Conclusions

In spot of what is often reported about the interoperability of the ISO 15926 in theoretical, the standard and its tools in practice have only offered simple interoperability between relational databases. In other words, they can exchange data between the objects of the same class (not inherited classes) with different properties. Users of iRINGTools should care about defined constraints on exchanged data. Some examples of these constraints could be the unit of measurement or propagation of common data between various tables of a database.

In addition, Part four and seven of the standard are still under development. In this regard, the ISO 15926 iRINGUserGroup gathers requirements from candidate companies in order to consolidate requirements and complete RDL and templates of the standard. Also, its tools require the collaboration and involvement of primary organizations as users of the standard.

Regarding the implementation of ISO 15926, iRINGTools could be the best solution because it is an open-source software being developed by initiators of the standard and in collaboration with other specialized companies. Generally, the standard and its tools are still not at the stage of providing accurate data interoperability between computer systems.

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Appendix A

Information concerning engineering, construction and operation of production facilities is created, used and modified by many different organizations throughout a facility's life cycle. The purpose of ISO 15926 is to facilitate integration of data to support the lifecycle activities and processes of production facilities. In general ISO 15926 consists of seven parts. The ISO published parts (currently parts one, two and four) can be bought from the ISO Store.
Unpublished parts of ISO15926 (Parts seven, eight and nine) are available for PCA members on the Members Area on the PCA website.

The ISO15926 standard is broken up into parts. In order to facilitate the explanation of the played role by each of these parts, an analogy in the English language will be used.

ISO15926 Part one - Overview and Fundamental Principles

Part one of the standard established the overall requirements for the representation of information associated with engineering, construction and operation of process plants. These requirements encompass all the phases of a process plant's/industrial facility life-cycle and the appropriate sharing and integration of data. Part one outlines concepts like 'data model', 'reference data' and 'templates' to be further developed in later parts of the standard.

ISO15926 Part two - Data Model

In the analogy to the English language, part two defines general categories of words such as verbs, nouns, adjectives etc.

This part specifies a conceptual data model designed to be used in conjunction with reference data. It provides the very top of the ISO15926 hierarchy of concepts, from which all reference data stems.

The model can support all disciplines and lifecycle stages, and also supports information about functional requirements, physical solutions, temporal data, and individual objects as well as activities; all of this at a very high level.

Although very flexible, this data model does little to reduce ambiguity for information exchange. For that, later parts of the standard are needed.

ISO15926 Part three - Reference Data for Geometry and Topology

In a book written in English, part three would provide the diagrams and pictures that make the text more comprehensive.

This part encompasses the basic concepts necessary for the description of geometry and topology. It provides the description of things like curves, surfaces, solid and also relationships between edges, faces and volumes etc.

Part three makes the concepts defined by ISO 10303-42 and ISO 10303-104, including concepts in Earth models and the GIS standards ISO 19107 and ISO 1911, available within the ISO 15926 environment.

A PCA Geometry Special Interest Group (SIG) is currently working on using Part 3 to cover the geometry of P&ID's and 3D models.

ISO15926 Part four - Initial Reference Data

The initial reference data from part four is equivalent to an English language dictionary. The name of the ISO15926 dictionary is Reference Data Library (RDL/WIP).

Also, as the English language evolves, new words are created by its speakers and added to the dictionary. In the world of ISO15926, this is why the term "Work in progress" (WIP) is found in many documents. The idea is that the ISO15926 dictionary is growing as new process plant concepts are needed.

The initial set of concepts published in part four will provide a solid basis for the organized creation and categorization of new process plant relevant concepts. This set amounts to approximately 10000 terms

ISO15926 Part six - Methodology for the Development and Validation of Reference Data

For a word to be added to the Oxford English dictionary it must satisfy conditions established by linguists. Part 6 is intended to cover the rules for creating and identifying new "words" to the RDL. This part if ISO15926 is currently under development. Its overall goal is to standardize the identification of new RDL term, establish the set of information that defines the term and lastly determine how to create metadata

ISO15926 Part seven - THIS IS WHAT YOU USE - Phrases

Part seven defines a few hundred templates that are used to build an information model. Like filling in the blanks in a phrase which might say “Centrifugal is a type of pump”.

Part eight+ is about how to use and access the data in the 15926 model, and how the RDLs grow over time to accommodate multiple languages, how to map other standards to 15926 and allow corporations to use and map their information into 15926.

Appendix B

The different levels are characterized as follows:

Level 0: Stand-alone systems have *No Interoperability*.

Level 1: On the level of *Technical Interoperability*, a communication protocol exists for exchanging data between participating systems. On this level, a communication infrastructure is established allowing it to exchange bits and bytes, the underlying networks and protocols are unambiguously defined.

Level 2: The *Syntactic Interoperability* level introduces a common structure to exchange information, i.e., a common data format is applied. On this level, a common protocol to structure the data is used; the format of the information exchange is unambiguously defined.

Level 3: If a common information exchange reference model is used, the level of *Semantic Interoperability* is reached. On this level, the meaning of the data is shared; the content of the information exchange requests are unambiguously defined.

Level 4: *Pragmatic* Interoperability is reached when the interoperating systems are aware of the methods and procedures that each one of them is employing. In other words, the use of the data – or the context of its application– is understood by the participated systems; the context in which the information is exchanged is unambiguously defined.

Level 5: As a system operates on data over the time, the state of that system will change. This change includes the assumptions and constraints that affect its data interchange. If systems have attained *Dynamic Interoperability*, then they are able to comprehend the state changes that occur in the assumptions and constraints that each one the systems are making over the time. When the *effects* of operations are vital, this kinds of interoperability becomes increasingly important. The effect of the information exchange within the participated systems is unambiguously defined.

Level 6: Finally, if the conceptual model – i.e. the assumptions and constraints of the meaningful abstraction of reality – are aligned, the highest level of interoperability – *Conceptual Interoperability* – is reached. This requires that conceptual models will be documented based on engineering methods; enabling their interpretation and evaluation by other engineers. In other words, for this level of interoperability, we need a "fully specified but implementation independent model" as requested.