GIMA
Geographical Information Management and Applications

Towards risk based pipeline integrity management through integrated use of heterogeneous SDI data sources

F.J. Westdijk
February 2015

Professor: prof. dr. ir. P.J.M. van Oosterom (TU Delft)
Supervisor: drs. ing. P.J. Baars (GDF SUEZ E&P Nederland B.V.)

Universiteit Utrecht
TU Delft
University of Twente.
Wageningen UR
GDF SUEZ

Towards risk based pipeline integrity management through integrated use of heterogeneous SDI data sources

A research into applying the SDI concept to offshore pipeline integrity management at GDF SUEZ E&P Nederland B.V. for the full life-cycle of the offshore pipeline object and its environment.

Date: 27 February 2015

Author: F.J. (Ferry) Westdijk

Studentnr: 9840974 (Utrecht University)

E-mail: ferrywestdijk@live.nl

Supervisor: drs. ing. P.J. (Peter) Baars
E-mail: peter.baars@gdfsuezep.nl

Professor: prof. dr. ir. P.J.M. (Peter) van Oosterom
E-mail: P.J.M.vanOosterom@tudelft.nl

Preface

Delft, 27 February 2015

Coming back from my MSc GIMA internship at the Ministry of Local Administration and Development in Damascus, Syria in 2009, I found myself at a crossroads. I had finished almost all of the MSc GIMA modules, and should be considering an MSc GIMA thesis research topic. However, getting back on track with daily life in the Netherlands appeared more difficult than I expected. It took me a while to get into the swing of things. Finishing MSc GIMA was not really an option during that time.

Before I knew it, I spent one year at Delft municipality, working for the maintenance department, one year as (assistant) land surveyor and almost four years at GDF SUEZ E&P Nederland B.V. as Marine Surveyor, while all this time, this one thing was still left unresolved: what to do with MSc GIMA?

In the meantime - civil war has set Syria ablaze, and my internship there seems like something from a distant, almost extraterrestrial, past - GDF SUEZ E&P Nederland B.V. has been so kind to offer me the opportunity to finally finish the MSc GIMA program, albeit that the research should be somehow related to the business processes. That's how this MSc GIMA thesis came to be.

I want to express my gratitude to all the people at GDF SUEZ E&P Nederland B.V., who have supported me to finally finish this thing, from the HR department, to my own department – Engineering and Construction. Off course special thanks goes out to Peter Baars, the "company mentor" ('supervisor is a bit of strange word'). Also thanks to Kees van Braak, the former department manager, who made me promise that I would finish the program. I'm indebted to Gerard van Soest, my 'line manager', for whenever I thought it was necessary, I was able to take the time for this thesis. Also thank you very much to my direct colleagues Bert de Vos, Jan Oostijen and Esther Grootjans for sticking up with me this long.

Peter van Oosterom deserves a very, very big thank you for getting me over the line - I know it must have been a hard job.

Last, but not least, I have received a lot of support from family and friends. Thank you very much! Without your support I wouldn't have been able to do this.

To finish off with words a wise man once spoke: het is geen friet bakken!

Summary

This MSc GIMA thesis report is the result of applied research into ways to make dispersed data available through the development of information infrastructure, rather than creating yet more copies of the existing data. The research was performed at GDF SUEZ E&P Nederland B.V. (company), to provide insights in the possibilities of implementing a SDI (Spatial Data Infrastructure) for offshore pipeline integrity management.

For an oil and gas company, availability of its pipeline network and the safety of transport of products are vital. Also for the environment it is essential that the pipeline network remains integer, without spillages and accidents. Furthermore, the company has an obligation to report the integrity status of the pipeline network to the authorities. For this reasons, the company has developed a comprehensive pipeline integrity management system as prescribed by company standards. A survey and inspection program and procedures are implemented.

These systems, programs and procedures require up to date and reliable data about the pipeline network and its environment. Up till now, this data has been dispersed over the organization. Different (sub)departments all deal with a specific part of the data and quite often, duplicate datasets are maintained, without proper version control. In order to ensure that everyone involved in pipeline integrity management has access to up to date and reliable data, improvement of the company's data management is required.

By developing a SDI for the company, supporting offshore pipeline integrity, this improvement is hoped to be achieved. The goal of this research is to demonstrate of the principle of data exchange and reuse through a SDI as a proof of concept. The SDI should provide the infrastructure to exchange data from different sources by arranging the organisational, institutional and technological requirements that are needed to exchange and access data.

In this research, two use case are developed to test a prototype SDI: 'dynamic seabed monitoring' and 'burial status of pipeline sections'. As offshore pipeline integrity depends partly on the direct environment of the pipeline, the interaction between the pipeline and the surrounding seabed is a central theme in the use cases. Also the conditions under which the company is allowed to operate the pipeline network as defined in permits play an important role in the use cases. Even more so, as in the future more elements from the environment might be included to come to a risk based pipeline integrity permitting and management system.

The first use case must demonstrate the SDI's capacity to serve bathymetric raster datasets of different periods in the same area including a 3D pipeline position. For some locations it is known from history that seabed conditions change rapidly. This poses a threat to the pipeline integrity and can result in a non-conformity with respect to pipeline burial requirements.The second use case must demonstrate the SDI's capacity to perform analyses on the most recent bathymetric data to come to a list of non-confirming pipeline sections. These are generally exposed and free spanning pipeline sections.

Three data sources that are actually in use at the company are selected to participate in the prototype SDI for pipeline integrity management:

- Pipeline data (Pipeline group)
- Seabed data (Survey group)
- Permit information (Legal department)

Information and data standards for each of the data sources are studied. Directly involved standards are PODS (Pipeline Open Data Standard) developed by the PODS association for pipeline data and SSDM (Seabed Survey Data Model) developed by the geomatics committee of the IOGP (International Association of Oil & Gas Producers, formerly known as OGP) for seabed survey data. Also (inter)national geographic information standards ISO 19100 series, the INSPIRE directive, NEN 3610, the Dutch IMKL (informatie model kabels en leidingen) and the ISO 19152 standard for Land Administration are consulted.

Selected standards are integrated in a model using UML and the data from the existing databases in the company is transformed to match the data requirements as stated in the conceptual model. As on-the-fly transformations were not possible due to time constraints, the research focused on datasets that were manually transformed to illustrate the proof of concept.

While combining bathymetry data from 2013 and 2014 with a 3D centerline and permit requirements in the SDI, a meaningful presentation of pipeline integrity related data is served that assists the pipeline manager in making vital decisions. Furthermore, by introducing spatial data about hazard zones, it has now become possible to start the transition towards risk based pipeline integrity management. This not only helps in giving suitable attention to previously unknown risks, it also helps the company to save on expenditures for the survey and inspection program.

During the research it has come to light that unknown data quality can seriously compromise the reliability of the SDI. An example is given of a 3D centerline of which the geometry was defined based on positioning data from the 1980's, during which period the accuracy was seriously below par if compared with current standards. Analysis on this kinds of data is not deemed viable, so recommended is that the company performs an update of its base data sources.

Interoperability through standardization has proven to be the key for developing the prototype SDI. However, the complex nature of the hierarchy of standards and the technical, specialized matter, make applying the standards into a difficult exercise. Reverse engineering had to be performed. This was made more challenging because of the large gap that exists between the hands-on applied industry standards and the complex hierarchy of geographical information standards. Two worlds collide, but the interface between the two worlds still needs to be defined. It is hoped that the industry standards gradually evolve along the contours of international geographic information standards, so that they too become interoperable.

This research concludes that institutional integration of the SDI concept is the deciding factor of its success. Technology is not the only issue. The awareness, recognition and willingness of key decision makers in the company is a starting point for the implementation of a SDI. Only when the concept of SDI gets institutionalized, actual companywide integration of heterogeneous data sources for no matter what business process through no matter what solutions can be realistically possible. This consists of various components, of which the definition and implementation of company policies regarding geographic information management and the adherence to (international) geographic information standards are the most important ones.

Samenvatting (Dutch)

Dit MSc GIMA afstudeerverslag is het resultaat van toegepast onderzoek naar manieren om data die her en der verspreid zijn, toegankelijk te maken zonder nieuwe kopieën van de data te creëren. Het onderzoek is uitgevoerd bij GDF SUEZ E&P Nederland B.V. om inzichten te verkrijgen in de mogelijkheden van het implementeren van een SDI (Spatial Data Infrastructure) voor offshore pijpleiding integriteit management.

Voor een olie en gas bedrijf is de beschikbaarheid van het pijpleidingnetwerk en de veiligheid van het transport van de gewonnen goederen essentieel. Ook voor het milieu is het van belang dat het pijpleidingnetwerk goed blijft functioneren, zonder lekken en ongevallen. Daarnaast heeft het bedrijf de verplichting de integriteitsstatus van de pijpleidingen te rapporteren aan de autoriteiten. Vanwege deze zaken heeft het bedrijf een pijpleiding integriteitsmanagement systeem ingevoerd, zoals ook voorgeschreven door de bedrijfsnormen. Zo zijn er een inspectie en een survey programma en procedures van kracht.

Dit systeem, de inspectie en survey programma's en de procedures zijn afhankelijk van betrouwbare en de meest recente data over het pijpleidingnetwerk en de omgeving. Tot op heden is deze data altijd verspreid geweest over verschillende (sub)afdelingen die allemaal een specifiek onderdeel van de data beheren. Overige partijen creëren regelmatig kopieën van de data, maar weten over het algemeen niet wat de betrouwbaarheid en geldigheid van de gegevens is. Om er voor te zorgen dat alle partijen kunnen beschikken over betrouwbare en de meest recente data is er een verbetering nodig van het data management systeem van het bedrijf.

Door het ontwikkelen van een SDI voor pijpleiding integriteitsmanagement wordt deze verbetering nagestreefd. Het doel van dit onderzoek is dan ook om het principe van data uitwisseling en hergebruik middels een SDI aan te tonen. De SDI zou de infrastructuur moeten bieden om data uit te wisselen door het regelen van de organisatorische, institutionele en technologische aspecten die nodig zijn voor het uitwisselen en benaderen van data.

In dit onderzoek wordt middels twee praktijkvoorbeelden een prototype SDI getest: 'dynamisch zeebed monitoring' en 'begraaf status van pijpleiding secties' Waar de integriteit van een pijpleiding beïnvloed kan worden door de directe omgeving, wordt de interactie tussen de pijpleiding en het omliggende zeebed centraal gesteld in dit onderzoek. Tevens wordt er gekeken naar de begraafvoorwaarden onder welke het bedrijf toestemming heeft voor het gebruiken van het pijpleidingnetwerk. Om nog een stap verder te gaan, zullen mogelijk toekomstige wijzingen van de wijze van bepaling van de begraafvoorwaarden meegenomen worden in dit onderzoek. Dit ter voorbereiding op het mogelijk introduceren van een risico gebaseerd pijpleiding integriteit management systeem.

Het eerste praktijkvoorbeeld moet aantonen dat de SDI de mogelijkheid heeft om bathymetrische datasets van verschillende periodes over dezelfde locatie aan te bieden in combinatie met de 3D positie van de pijpleiding. Van sommige locaties is bekend dat de zeebodem zeer dynamisch is, waardoor de begraafcondities van de pijpleiding snel kunnen veranderen. Dit kan een bedreiging vormen voor de integriteit van de pijpleiding, tevens bestaat het gevaar dat de pijpleiding niet meer voldoet aan de gestelde gebruiksvoorwaarden.

Het tweede praktijk voorbeeld betreft de mogelijkheid van de SDI om analyses uit te voeren over de begraafcondities van de pijpleidingen op basis van de meest recent verkregen bathymetrische datasets. De SDI moet in staat zijn om een lijst op te stellen van pijpleiding secties die niet voldoen aan de gestelde vergunningseisen. Dit betreft meestal blootliggende

of zelfs vrij spannende pijpleidingen. Drie data bronnen die daadwerkelijk in gebruik zijn bij het bedrijf zijn geselecteerd voor het testen van het prototype SDI:

- Pijpleiding data (Pipeline group)
- Zeebed data (Survey group)
- Vergunningsinformatie (Legal department)

Standaarden voor het modeleren van elk van deze drie type data zijn bestudeerd. Het betreft in eerste instantie het PODS (Pipeline Open Data Standard) data model van de PODS associatie voor pijpleiding data en het SSDM (Seabed Survey Data Model) data model van de IOGP (International Association of Oil & Gas Producers, formerly known as OGP) voor zeebed data. Tevens zijn diverse (inter)nationale standaarden bestudeerd, zoals de ISO 19100 serie voor geografische informatie, het INSPIRE directive, de NEN 3610, het Nederlandse IMKL (informatie model kabels en leidingen) en de ISO 19152 standaard voor kadastrale registratie (vergunningen).

De standaarden zijn middels UML gecombineerd in een conceptueel model en de bestaande data uit de verschillende databases is getransformeerd naar de definities van het model. On-the-fly transformatie is hiervoor mogelijk, er is echter gekozen om handmatige transformatie van data toe te passen om het SDI principe aan te tonen.

Door het voor de praktijkvoorbeelden SDI combineren van bathymetrische data uit 2013 en 2014 met een 3D centerline en vergunningseisen, is een betekenisvol plaatje ontstaan. Dit plaatje kan de pijpleiding manager helpen bij het maken van belangrijke beslissingen. Bovendien, door het toevoegen van data over gevaarlijke gebieden, kan aangevangen worden met de introductie van risico gebaseerd pijpleiding integriteitsmanagement.

Tijdens het onderzoek is duidelijk geworden dat onbekende data kwaliteit een ernstige inbreuk op de betrouwbaarheid van de SDI kan zijn. Een voorbeeld wordt gegeven van een 3D centerline waarvan de geometrie gebaseerd is op positioneringsdata uit de jaren tachtig. In vergelijking met de huidige tijd, is de accuratesse van die positioneringsdata ondermaats. Als dergelijke data gebruikt wordt in de SDI, is verdere analyse niet aan te raden. Het bedrijf wordt aangespoord om de data kwaliteit van de 3D centerlines te verbeteren.

Interoperabiliteit door standaardisering is heel belangrijk gebleken voor de ontwikkeling van het prototype SDI. Echter, de complexiteit van de datastandaarden en hun onderlinge hiërarchie en het gespecialiseerde technische karakter van de standaarden, dragen niet bij aan de realiseerbaarheid. Reverse engineering is uitgevoerd hetgeen een grote uitdaging was, gezien de grote afstand die bestaat tussen de hands-on geïmplementeerde industrie standaarden en de complexe, meer abstracte geografische informatie standaarden. Twee werelden lijken te botsen omdat er geen gemeenschappelijke taal bestaat. Het is te hopen dat de industriestandaarden op termijn het voorbeeld van de geografische informatie standarden raamwerk volgt. Alleen op die manier zou interoperabiliteit van de industrie standaarden gestalte kunnen krijgen.

Het onderzoek concludeert dat institutionele integratie van het concept van een SDI de bepalende factor is voor het succes ervan. Technologie is een van de aspecten. Het is de bewustwording, erkenning en de bereidheid van beslissingsnemers in het bedrijf die het startpunt kan vormen voor het succesvol implementeren van een SDI voor pijpleiding integriteits management. Slechts dan wanneer het SDI concept geïnstitutionaliseerd raakt, kan daadwerkelijk bedrijfsbreed integratie van verspreide databronnen plaatsvinden. De middelen waarmee dat gebeurt zijn daarbij niet van groot belang. Het is veeleer de definitie van bedrijfsbeleid en het hanteren van standaarden die het mogelijk maken om data uit te wisselen en te hergebruiken.

Table of contents

List of figures

Terms & Abbreviations

Term	Definition
APDM	ArcGIS Pipeline Data Model
API (1)	American Petroleum Institute
API (2)	Application Programming Interface
ASME	American Society of Mechanical Engineers
BevB	Besluit externe veiligheid Buisleidingen
CAD	Computer-Aided Design
CEN	Comité Européen de Normalisation; European Committee for Standardization
Company	GDF SUEZ E&P Nederland B.V.
Corporate	GDF SUEZ Group
DNV	Det Norske Veritas
DSV	Diving Support Vessel
E&P	Exploration and Production
ED50	European Datum 1950
EPI	Exploration and Production International
ERP	Emergency Response Procedure
ETRS89	European Terrestrial Reference System 1989
GIMA	Geographical Information Management and Applications
GIS	Geographic Information System/Science
GML (1)	Geography Markup Language (ISO 19136)
GML (2)	Generalized Markup Language (ISO 15926)
GOIMS	GDF SUEZ E&P Operational Integrity Management Standard
HSEQ	Health, Safety, Environment, Quality
HTML	HyperText Markup Language
ID	Identification
IMKL	Informatie Model Kabels en Leidingen;
IMPS	Integrity Management Pipeline Systems
INSPIRE	Infrastructure for Spatial Information in Europe
iRING	ISO 15926 Realtime Interoperability Network Grid
ISO	International Organization for Standardization
LADM	Land Administration Data Model
LAT	Lowest Astronomical Tide
MSL	Mean Sea Level
NEN	Nederlandse Norm; Dutch Standard
OGC	Open Geospatial Consortium
OGP	International Association of Oil & Gas Producers
PIMS	Pipeline Integrity Management Standard
PODS	Pipeline Open Data Standard
QRA	Quantative Risc Analysis
ROV	Remotely Operated Underwater Vehicle
SDI	Spatial Data Infrastructure
SCADA	Supervisory Control And Data Acquistition
SODM	Staatstoezicht op de mijnen; State supervision of mines
SQL	Structured Query Language
SSDM	Seabed Survey Data Model
URL	Uniform Resource Locator
W3C	World Wide Web Consortium
WION	Wet Informatie-uitwisseling Ondergrondse Netwerken; Act on the information exchange of underground networks
XML	Extensible Markup Language

1. Introduction

This chapter presents the research motivation and background (section 1.1), then it defines the research problem (section 1.2), and objectives (section 1.3). Next the research question and sub-questions (section 1.4), the methodology (section 1.5) and the scope (section 1.6) are described. Finally, in section 1.7, the remaining chapters are introduced.

1.1. Motivation and background

GDF SUEZ E&P Nederland B.V. is one of the largest natural gas producers in the Dutch sector of the North Sea, operating a network with more than thirty offshore platforms and over 1600 km of pipelines. For an overview of the network see Figure 1.

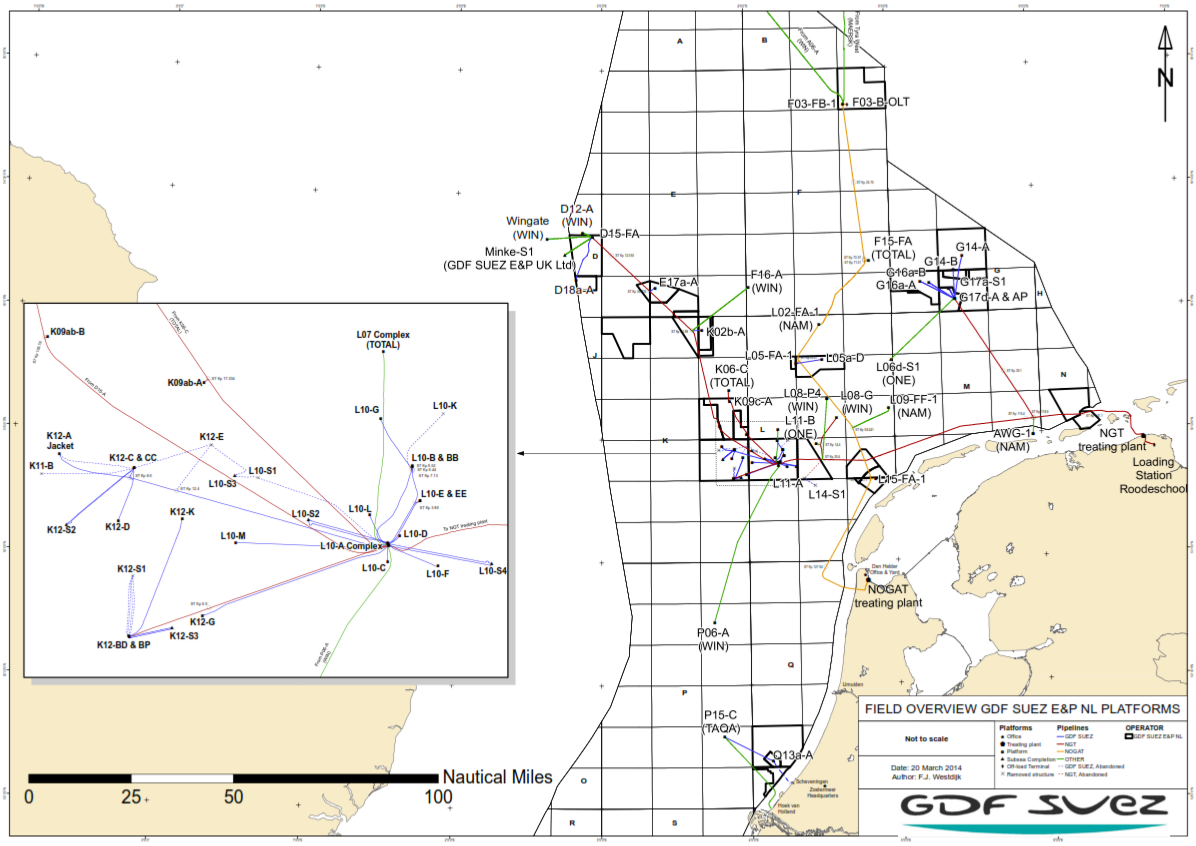


Figure 1: Overview of company platform and pipeline networks

The availability of this network and the safety of transport of products are vital for the company. Without the availability and safety, the core business of an E&P company cannot be sustained. Integrity of the involved assets is paramount for safe operations. Company and corporate policies recognize this and incorporate various standards to deal with the operational integrity of the network assets and the safety of the processes involved. In these standards asset integrity is defined as: "*The ability of an asset to perform its specified function effectively and efficiently whilst safeguarding life and the environment.*" (GDF SUEZ, 2012, p. 11).

As part of the group Health, Safety and Environment (HSE) Policy and the group HSE Management system, a Group Operational Integrity Management Standard (GOIMS) is defined to come to a systematic approach towards achieving good practices in asset integrity and process safety management. The standard describes at an abstract level 14 key elements[1] that should be applied to asset-specific sub-standards. See Figure 2 for the various sub-standards that are identified.

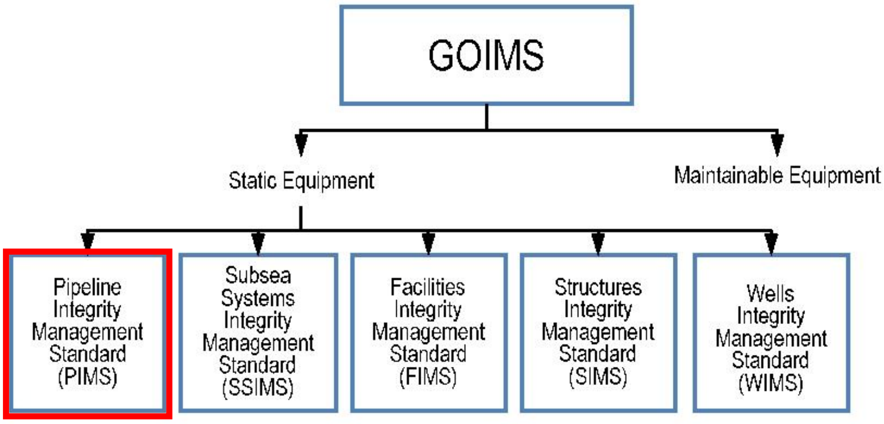


Figure 2: GOIMS and its sub-standards; taken from (GDF SUEZ, 2014)

For the availability and safety of pipeline networks, the applicable standard is the Pipeline Integrity Management Standard (PIMS, see (GDF SUEZ, 2014)). In this standard the 14 abstract key elements of GOIMS are made concrete by identified aims, mandatory requirements and expectations per key element. It describes the system of control and management necessary to maintain the integrity of pipelines through '*People, Plant, Processes and Performance*' (GDF SUEZ, 2013, p. 16), to make clear who should be doing what (to which assets) including when it should be done, how it should be done and why it should be done.

1.2. Problem definition

What is not included in the standards, is with what tools, instruments and methods the aims, requirements and expectations should be used and met. To be specific: Key element 10 details Information, Documentation and Effective Communication. The aim of this element is to identify, maintain and safeguard important information and to ensure personnel can readily access and retrieve critical records for pipelines. In the requirements of this key element, data collection and storage systems (asset registers) are mentioned, but no details are given about what data and how the access to the information and data in those systems should be arranged.

Nonetheless, in key element 12 (Engineering (Design), Construction, Installation, Operation, Maintenance, Assurance and Decommissioning), the expectation is expressed that "*a strong interface shall be established between engineering, design, operations and commercial teams*" (GDF SUEZ, 2013, p. 42). Access to the information and data in systems by and from various parties is a prerequisite for such a strong interface. Ideally, the interface provides a multi-view perspective on the information and data in the various systems by different disciplines and parties, using whatever application to access it, to see whatever combination of available information and data that is necessary. This research is about finding a way to realize the required multi-view perspective.

Combining data from different sources is a topic that receives ample attention in both management and science communities. The main question is how to access data that is stored

[1] See Annex I for the definition of the elements

in different types of databases and files, that is physically at different locations, that can all have different structures and of which the quality and reliability is not always known, without creating yet another (manipulated) copy of the data or yet another system. Proposed is that a SDI (Spatial Data Infrastructure) provides a solution for this question: it is "*an integration platform that facilitates interoperability and the interworking of functional entities within a heterogeneous environment.*" (Rajabifard, 2008, p. 16).

This research starts with the hypothesis that SDI development is a valid solution for the data management issues as stated above. To test this hypothesis, focus is on SDI development for the corporate environment of the company.

1.3. Research objectives

The main objective of this research is to demonstrate the added value and principle of data reuse and exchange by means of a SDI (Spatial Data Infrastructure) in the context of offshore pipeline integrity management in a corporate environment, from a technical data management perspective. This SDI should be able to perform like the interface as mentioned in the aim of key element 10 and the expectation of key element 12 of the groups PIMS standard.

Commonly recognized components of an SDI are depicted in Figure 3.

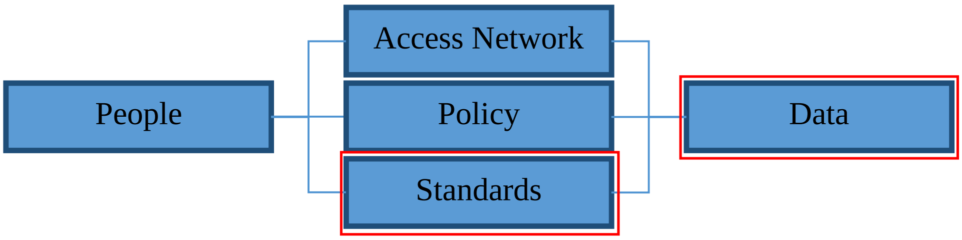


Figure 3: SDI nature and components; taken from Rajabifard (2008), p. 13

Through providing the infrastructure for reusing and exchanging data from different sources by arranging the organisational, institutional and technological requirements (see (Rajabifard, 2008, p. 13)), the SDI can become the nerve system of the company. It should define how and which information and data from which existing sources and systems should be shared as a means to make the existing systems inter-operate to support offshore pipeline integrity management in this specific case. Other uses are considered future work, but are highly recommended.

The key feature of an SDI is that it uses services to deliver required data from distributed data sources through a network to the user. These services can only function properly when standards are adhered to and policies are in place. Later on in this report (section 2.3), the SDI components are explained further and applied to the research context of offshore pipeline integrity management at company. This research is focusses on the technical data management issues that are related to the development and implementation of a SDI in a corporate environment. Emphasize is explicitly on the SDI components Standards and Data.

This research should make clear how existing data from different sources can be accessed and used without making yet another copy or yet another system. The key issue is that the data that is already in use for specific applications can be used in different ways by taking it out of its original context and combining it with data from other sources. The data remains to be kept in its original location conform its own standards and maintained by the original owners, applications and processes.

1.4. Research question and sub-questions

The research question for this thesis is:

> ***How to realize integrated use of heterogeneous offshore pipeline integrity data resources to support pipeline integrity management throughout full life cycle of the offshore pipeline object, according to SDI principles?***

Although geographical data and information is placed at the center of the research by mentioning SDI principle in the research question, attention will also be given to non-geographical data and information, since a considerable part of the company's systems and current industry standards neglect the spatial nature of the data and information.

The research question is directed at a practical, real life corporate situation. The result should also be practical for implementation at the company. However, the scientific component of this research is even more relevant: this research in this context should provide insights in the main processes and issues that play a role in the application of the SDI principles in a real life, corporate environments. The research question and the sub-questions should be read in this light.

Sub-questions

The following sub-questions are formulated to answer the main research question:

Sub-question 1: What is the full life-cycle of an offshore pipeline and what stages in that life cycle-can be identified?

In order to understand the specific details and data requirements for offshore pipelines, the different stages of the life-cycle are to be understood in relation to core business processes. It should get clear how, why, using what data and by whom a pipeline gets operated. Also the relation of a pipeline with its environment – most notably the seabed – and involved legal issues (permits) and standards are to be clarified.

Sub-question 2: What actors, processes and heterogeneous data sources are involved in offshore pipeline integrity management?

This sub question should give insight in the meaning of offshore pipeline integrity management at the company, especially in the involved actors, processes and data. Combined with the information of sub-question 1, this information should be the starting point for defining basic requirements of a SDI.

Sub-question 3: What are SDI principles and how can they be applied in the context of this research?

Since the research starts from the hypothesis that a SDI is a valid solution, the main building blocks of SDI's must be discussed. Applying these main building blocks by defining and identifying them in the context of the research, should make clear which issues are involved in SDI development. This research focusses mainly on the technical data issues, so most attention will be given to the SDI components Data and Standards.

Sub-question 4: What methods and standards for data modelling for the pipeline object, seabed data and permit information can be used in the research context and how can they be integrated?

By answering this sub question, knowledge about methods and standards to model different kinds of data will be generated. With this knowledge, an assessment can be done of which standards and models are most applicable or appropriate for the specific data requirements. Furthermore, it should be made clear how models for different data sources can be integrated in one combined model.

Sub-question 5: How can an integrated data model be tested and assessed?

If an integrated model is developed, it has to be tested, assessed and evaluated by a practical method. Assessment and evaluation results can be used for further application and implementation of the proposed method in this research.

1.5. Methodology

The main methodology of the research is the development, assessment and evaluation of a prototype for an integrated data model for offshore pipeline integrity management. To come to the development of such a data model, knowledge of the research context and experience with technology is required. This knowledge and experience should be the result of answering the sub-questions and applying learned MSc GIMA insights in the context of this research.

For each (sub)-question a method is described.

Sub-question 1: What is the full life-cycle of an offshore pipeline and what stages in that life cycle-can be identified?

By doing informal interviews with various actors in the company combined with a desktop study and the experience of the researcher at company, required information is collected. Chosen is for informal interviews with stakeholders in the company since the information is only meant as research background, although formal and (semi-)structurized interviewing or using questionnaires was considered.

Sub-question 2: What actors, processes and heterogeneous data sources are involved in offshore pipeline integrity management?

By doing a desktop study into offshore pipeline integrity management standards, various informal interviews with the pipeline manager and pipeline integrity engineers, information is collected for creating a use case diagram portraying actors, processes, data and relations between those elements involved in offshore pipeline integrity management.

Sub-question 3: What are SDI principles and how can they be applied in the context of this research?

Performing a literature study into SDI theory and enterprise interoperability results in an overview of components, methods, frameworks, technologies and standards for interoperability at the corporate level. These are used in the context of this research by the identified actors, processes and data sources of sub-question 1 and standards and models of sub-question 4.

Sub-question 4: What methods and standards for data modelling for the pipeline object, seabed data and permit information can be used in the research context and how can they be integrated?

Performing a literature study into standardization, focusing on industry standards, (inter)national geographical information standards, domain/application standards and their relation, results in knowledge of existing standards.

Different models are to be combined in a conceptual model using UML. If the same objects are part of different models, one of the techniques to combine the models is model to model mapping.

The last step for this sub-question is implementing the conceptual model in a technical model, which is used to structure the actual data in a test environment. An example of this is provided in the description of the development of the LADM for Malaysia (see (Zulkifli, et al., 2014)).

Sub-question 5: How can an integrated data model be tested and assessed?

In the test environment with the implemented technical data model, real-life data is used to test the prototype with the two use cases that are based on the requirements that are formed on basis of sub-questions 1 and 2.

The two use cases that are formulated are:

1. Use case 1: monitor dynamic seabed conditions at known locations
2. Use case 2: find non-complying pipeline sections

In section 3.4 the use cases are described and in section 6.2 the use cases are used to test the prototype.

Theoretically, the results from these tests are used to come to technical refinements of the model. This can be an iterative process in which the data model is made more and more suited for the context with each test. Even more use cases might be considered if an extension of the model is required for future work.

1.6. Scope of research

The scope of this research is the demonstration of the principles of a SDI – a proof of concept – applied to offshore pipeline integrity management, without actually implementing the SDI at the company. Implementing services for the specific context at the company is a technical issue and could be the result of the findings of this research. What this research hopes to demonstrate, is the possibility of accessing and combining data from various sources about the pipeline object and its environment without creating yet another system or copy of existing data.

The scope of this research encompasses the development, assessment and evaluation of a conceptual model for offshore pipeline integrity management as a specific part of a companywide data model. (Inter)national and sector based data standards and their models are studied to find out if and how it is possible to combine or integrate the standards and their models in a conceptual model for offshore pipeline integrity management.

Furthermore, integration of the offshore pipeline integrity management model in a companywide SDI is considered so that information and data from existing systems can be exchanged between those systems. As this company wide data model and data infrastructure do not exist yet during this research, it is assumed as a possible future development.

Although different data sources that have to do with the offshore pipeline and its environment are discussed, only data that is directly involved in integrity management of the offshore pipeline during the operations and maintenance phase is described in detail. Three existing data sources have been selected:

1. Offshore pipeline centreline geometry
2. Seabed survey data
3. Permit information

By focussing on these three data sources for the model, an example is given of how to apply the principles of a SDI to a corporate context. Further extending the model with different kinds of data to cover the full offshore pipeline object life-cycle would be the next step for this particular context. Insights and experience during this research would be a valuable asset for that operation.

As the selected data sources are actually in use in the company systems and direct, untested changes of the data or systems are not an option. It is decided to duplicate the relevant parts of the company's systems, so that a test environment is created for this research. Assessment and evaluation of the model will take place by applying the model and data to the proposed use cases in the test environment.

Topics outside of the scope

While this research is designed to be as complete as possible to answer the research questions, some related topics are considered outside of the scope of this research. Some of these topics are recommended as future work in the concluding chapter of this report. Topics outside the scope of this research are:

- Changes to existing company systems, data and infrastructure
- Implementing services in the company's infrastructure
- The development and implementation of a companywide SDI
- The integration of the offshore pipeline integrity management model in a companywide SDI
- Extending the model with other than the selected data sources
- (Development of) assessment and evaluation methods for the SDI, other than the application to the defined use cases
- Doing iterating testing of the model
- On-the-fly data transformations (e.g. through HALE)
- Software programming
- Developing extensive SQL statements
- Modelling the pipeline object as a network object
- Defining data requirements based on pipeline integrity management standards like:
    - NEN 3650 series
    - prEN 16348
    - ISO 19345
    - ASME B31 8S
    - DNV-RP-F116

- Specialized (hydrographical, geomorphological) analysis of data results
- The definition of company/corporate policies for geographical information management and exchange
- (Policies for) Exchanging data with external parties
- (Standards for) Portrayal and representation methods

1.7. Remaining chapters

In the remainder of this report the results of these steps are presented and assessed. At the end a conclusion with recommendations is give. Each sub-question is translated in a chapter or section. The structure of the report is as follows:

Chapter - 2 - **Background of research: Offshore oil and gas pipelines** - deals with the justification and relevance of research. The general company processes are briefly presented and the object life-cycle of a pipeline and its stages are discussed. Also, as a frame of reference, the basic SDI components are applied to the research context.

Chapter 3 - **Offshore pipeline integrity management** - zooms in to pipeline integrity management by defining existing actors, processes and data sources involved. The chapter concludes with the introduction of the 2 use cases which are used to test the proposed SDI prototype.

Chapter 4 - **Corporate SDI - Interoperability at the corporate level** - is a justification for the use of the concept of an SDI. It explores current methods and technologies to make corporate information systems interoperable. It focuses on the nature of a SDI and data exchange and reuse. Current technological developments in the field of enterprise architecture and interoperable systems, are briefly discussed. The chapter ends with discussing semantic interoperability as one of the main parts of a SDI.

Chapter 5 - **Modelling the pipeline object, seabed data and permits** - explores methods and standards for modelling the involved data sources - the pipeline object, seabed data and permit information. From the inventory of which standards are available for modelling involved data sources an assessment of suitability and achievability is made. As a conclusion, the model for the prototype SDI is presented.

Chapter 6 - **Proof of concept** - tests the proposed prototype SDI against the use cases as presented in chapter 1. Actual ‘live’ data from the company is used to assess to working concept of the prototype SDI.

Chapter 7 - **Conclusion and recommendations** - presents the research findings. The research question and sub-questions are answered. Moreover, this chapter is a reflection on the research process, main steps and choices. Furthermore, a list of recommendations is drafted for further study and implementation of an actual SDI at the company.

2. Background of research: Offshore oil and gas pipelines

This thesis research is not about a fictional case. Real life issues and work processes are involved that are essential for the company. As was stated in the introduction, the availability of the pipeline network and the safety of transport of products are vital for the company. Pipeline integrity management is in place to safeguard this availability and safety. A SDI to support this could seriously contribute to pipeline integrity management in the company.

As an introduction to the overall context of the research, this chapter describes the company's main processes, the pipeline object life-cycle and the identified SDI components. This chapter starts with a brief description of the life cycle of the main process of the company: the development of oil and gas production projects (section 2.1). Next the life cycle of a pipeline is presented (section 2.2) and finally the SDI components are described and identified in the research context (section 2.3).

The next chapter zooms-in on offshore pipeline integrity management during one stage of the offshore pipeline's life-cycle by identifying involved actors, processes and data resources. It also presents two use cases.

2.1. Context: the oil or gas development process

The life cycle for the development process of the company is depicted in Figure 4:

Figure 4: GDF SUEZ E&P business development process; taken from (GDF SUEZ, 2011)

This is the process of identifying, extracting and selling gas or oil from prospect to a completed well.

A. Exploration

By seismic research potential reservoirs can be identified. When a prospect (a promising reservoir) is identified in exploration studies, an exploration well proves the existence of oil or gas. For this an exploration concession, given by the authorities is required. Next an appraisal well assesses the characteristics of the oil or gas. When the analysis of the appraisal well indicates economically viable production, a field development plan is drafted. After a management decision and government approval, the development phase might start and a production concession can be requested at the authorities.

B. Development

The infrastructure to extract and transport oil or gas is designed. This usually consists of a production well, a platform with a treatment system and a tie-in on the existing pipeline transportation and distribution networks. When the designs are ready, permits for construction are requested. After award of permits, the infrastructure is constructed. This generally involves the construction of a new pipeline section.

C. Production

When the infrastructure is constructed, tested and deemed fit for use and the minister of Economic affairs has agreed, production can start. Oil or gas is extracted from the reservoir and transported through the pipeline network. All assets fall under their respective operation and maintenance regimes.

D. Sales
Contracts for the delivery of the oil or gas are made. Prices, gas composition and quantities, delivery dates etc. are defined. This is the phase that should deliver return of investment for the company.

E. Abandonment
After the well stops producing, plans are made to abandon the development. Abandonment of the assets is eventually also part of this phase.

2.2. Pipeline life cycle
In this section, the pipeline life-cycle is presented. Every stage in the life-cycle gets attention, although the scope of this research is limited to the operations and maintenance stage. For the definition of the stages, NEN 3656 (in development) is consulted, see (NEN 3656, 2014, p. 9). The life-cycle of a pipeline is presented in Figure 5.

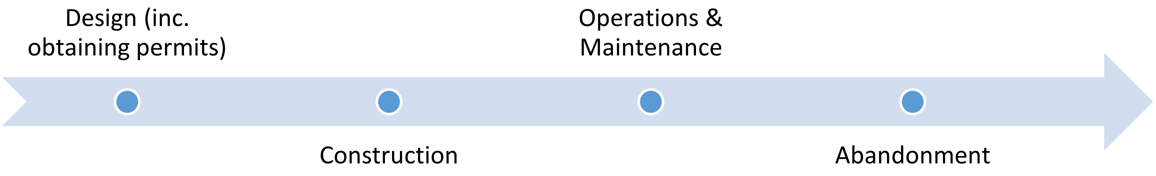


Figure 5: Pipeline life-cycle according to NEN 3656

A. Design
During the design stage, the pipeline gets defined. The steps of definition are from field development plan through pipeline specifications and design appraisal to the permit for construction given by the authorities.

A.1. Route options for the field development plan
For the field development plan, various options for the pipeline route are presented. The survey department constructs the routes in ArcGIS. Start and end point are given and various practical considerations such as crossings with existing infrastructure and navigability for construction vessels determine the proposed routes. The length of the pipeline, the number of crossings and the tie-in method determine the estimated costs for the options. For more information about the process of defining the geometry for pipeline route options, see Annex III.

In the field development plan, the most favorable option for the pipeline routing is chosen and the other options are discarded. When the field development plan has been accepted by the company and its partners, a FID (final investment decision) is released and the realization of the project can start, with the chosen option for the pipeline routing.

A.2. Detailed pipeline design
A detailed design of the chosen option for the pipeline routing will be made by a selected engineering company. First a pipeline basis for design, describing all engineering requirements, such as regulations and guidelines, seabed geology, design criteria (gas temperature, gas composition), environmental data, cathodic protection, will be agreed upon. Next all required data is collected and the engineering company finalizes the detailed design report in close consultation with the company and an independent certifying institute.

A.3. Survey data
One of the inputs for the detailed design is geophysical and geotechnical survey data. The survey department drafts a pipeline route survey program and contracts a survey company to acquire, process and deliver the data. Currently the data format is .pdf report and .dwg drawings.

A.4. Design appraisal
An independent certifying institute has to approve the detailed design report in a design appraisal before the authorities can give a permit for construction. The design appraisal contains the detailed design report with pipeline specifications, but also the testing and inspection plans. Standards that are used for the appraisal are NEN 3656 and DNV 101. These standards refer to (among other issues):

- Geotechnical data (soil)
- Risk analysis
  - 10^{-6} fail chance
  - Minimal burial depth for pipelines smaller than sixteen (16)"
  - Pipe movement and stresses by temperature changes due to production startup
  - Shipping intensity and anchorage
- Abandonment plan

A.5. Permit for construction
The construction manager at the company has to request a permit to construct the designed pipeline, based on the design appraisal and all design documents.

B. Construction
During the construction stage a pipeline gets assembled. Production of a pipeline involves fabrication and procurement of pipe joints, an offshore pipelay operation, pressure and leak testing, pipeline burial and should result in a permission by the authorities to put it into use.

B.1. Procurement
With the design appraisal the specifications for pipe material (composition, wall thickness) are approved and the pipe joints can be procured. As the fabrication of the pipe joints can take a long time, the pipe specifications are often released earlier. At fabrication every individual pipe joint gets a unique code and a certificate.

B.2. Offshore pipelay operation
During the offshore pipelay operation every joint gets welded into its predetermined position by a pipelay vessel. The vessel guides the pipeline towards seabed in combination with a diving support vessel (DSV) and ROV (remotely operated underwater vehicle). When all joints are welded together, the whole pipeline is pressure tested. Next, to connect the pipeline to the platform riser, spool pieces are installed by a DSV and ROV. These prefabricated spool pieces are adjusted based on the metrology (exact dimension between laydown head of the pipeline and a fixed point the platform).

B.3. Certificate of fitness
The whole pipeline is then leak tested. When both the pressure test as well as the leak test is successful, a certificate of fitness (fit for use) is given by the independent certifying institute.

B.4. Pipeline burial

When the detailed design of the pipeline includes burial conditions, the pipeline needs to be buried. Depending on soil type, the correct burial type and equipment – usually trenching equipment in combination with a diving support vessel (DSV) and ROV (remotely operated underwater vehicle) – is selected and the burial executed. Near the platforms, pipeline spool pieces get rockdumped for protection and load against pipeline displacement due to temperature changes at operation. Also at specific locations identified after the trenching as OOS (out of straightness) locations, rockdumping may be performed to prevent upheaval buckling due to temperature changes at operation.

B.5. Permission to put the pipeline into use

A formal request is issued to the Minister of Economic Affairs, including a longitudinal profile of the pipeline after burial, the certificate of fitness and other relevant documents, who in turn grants permission to put the new pipeline into use.

B.6. As-built data

All as-built data is processed and compiled in a complete as-built report of the pipeline. The drawings of the as-built report get stored in the company's drawing control system. Reports are stored on company's file servers. Proper document control is to be implemented. Data usually involves excel sheets with as-laid and as-trenched events (horizontal and vertical position, relation to surrounding 'natural' seabed, details about soil conditions during trenching). Also all diving related data (logs, videos) gets transferred. Excel sheets and as-built drawings are used to update company's pipeline management software and databases.

C. Operations & Maintenance

After commissioning and hand over of the pipeline to the production department, the operations and maintenance stage starts. During this stage the pipeline is actually in use. The pipelines group in the company is responsible for maintenance and integrity management of the pipeline.

C.1. Commissioning

During the whole life of the pipeline until the operations and maintenance stage, commissioning is involved. However, it is only at the actual commissioning of a pipeline that it is completely finished and the pipeline gets filled with the produced gas or oil for the first time. All documents, permits, test reports, certificates etc. must be in place and the construction of the pipeline and all associated facilities must be completely finished.

C.2. Production

The usage of the pipeline is controlled by the production department. The dispatch department generates a model of required volumes and compositions, based on commercial contracts and the production department runs this model to deliver the products as specified. A SCADA system is in place to support the control of the production. This system uses data from metering stations, pressure and temperature gauges, flow rates, pumps, compressors etc. to control the usage of the pipeline.

During the production process, pigging of the pipeline might be required for the optimal operability of the pipeline. In case of gas pipelines, multiphase flows might compromise the operability – so called slugging. By deploying a pig, the gas concentrate is pushed out of the pipeline. A slug catcher must be installed to receive the slug.

C.3. Integrity management

When oil or gas flows through the pipeline, safety of operations and integrity of assets is vital. The company's HSE (Health, Safety and Environment) department is responsible for the overall integrity of operations. The HSE Management system (GDF SUEZ, 2012) controls this integrity. The pipeline group is responsible for the integrity management of the pipeline assets. This includes emergency response preparations, emergency repair support, corrective and periodic maintenance programs (using Maximo), periodic survey and inspection programs, communication with and reporting to authorities and the asset management system. All these issues are integrated in an Integrity management system and an integrity management standard (GDF SUEZ, 2013) prescribes how to address the issues. A pipeline integrity handbook describes involved personnel, responsibilities and processes. Chapter 0 describes the integrity management processes in more detail.

Maximal allowable free span

From a pipeline integrity management point of view, burial of pipelines is critical for the protection of the pipelines against fishing gear, dragging anchors, lost cargo, grounding ships, etc. Another critical element is the length in which a pipeline is spanning free from the seabed. When a pipeline is not fixed on or in the seabed, vibrations of the pipe might be incurred by currents and vortexes around the pipe. These vibrations can deteriorate the pipeline integrity at that location greatly.

C.4. Survey and inspection programs

As part of the integrity management on the one hand and to comply with regulations on the other, company performs periodic survey and inspection programs. These programs are to verify the integrity of the pipeline. The programs that are in place are acoustic survey, visual inspection and inline inspection. Results of the surveys and inspections are assessed yearly and the results are send to the authorities. A remedial work list is drafted, stating measures for each non-conformity. This can be monitoring, but also perform corrective maintenance.

C.5. Acoustic survey

Acoustic surveys are performed yearly over all the company pipelines, from riser to riser or sidetap or beach landing, to map the seabed in the near vicinity of company pipelines, to identify seabed features (scouring, trawling scars, debris) and to establish the depth of burial of company pipelines. The purpose of the survey is to detect the horizontal and the vertical position and configuration of company pipelines by means of side scan sonar (SSS), sub-bottom profiler (SBP), multibeam echosounder (MBE) and single beam echo sounder (ES), deployed from a suitable survey vessel, which position is accurately known by means of a DGPS positioning system.

Results to be obtained are vertical and horizontal positions of all pipelines, umbilicals and (telephone) cables. Regarding sea lines, particular attention is to be paid to pipeline and umbilical freespans and exposures. In addition to bathymetry data, the information to be supplied is: the length of unsupported pipe, the height of free gap under the pipeline, the distance of top pipeline and umbilical relative to natural undisturbed seabed, the thickness of coverage, the width and depth of trenches, the horizontal distance at "crossing points" between pipelines and pipelines and/or (telephone)cables.

The acoustic survey program scope is sometimes extended with a cathodic protection survey. Using the same vessel, the state of the pipelines cathodic protection system is assessed.

C.6. Visual inspection

By means of diving or ROV (remotely operated underwater vehicle) inspection, the pipeline gets a periodical check. The visual check is to establish information about the structural integrity, marine growth, coating damage, external corrosion, denting and other issues of the pipeline up to 30 meters away from the platform. The inspection is performed with a suitable DSV (diving support vessel) and certified divers and/or inspection class ROV.

C.7. Inline inspection

Another inspection method that is applied to assess conditions of coating, corrosion, wall thickness, pitting, denting and geometry is inline inspection. A sophisticated tool with all kinds of sensor passes through the pipeline by means of pressure. During its run, the tool records data. During post-processing, the data is related to the pipeline by the measurements of a set of wheels, an inclinometer and an accelerometer in the tool. These wheels record the traversed distance, the inclinometer and accelerometer the changes in direction.

This method of inspection is not used regularly yet by company, but usage is expected to grow in the coming years.

C.8. Preventive and corrective maintenance

A program for preventive maintenance is in place for every asset. Corrective maintenance is performed when as a result of the inspection program a non-conformity is identified. In case of corrective maintenance based on an acoustic survey, first a visual inspection by diving is performed to assess the severity. Usually this consists of a weight coating check, sometimes in combination with concrete matrass installation to remedy a coating loss.

In a combined program, the reported non-conformities receive corrective maintenance. Mostly this means rockdumping. By rockdumping exposed sections of pipelines get buried under a dump of rocks.

C.9. Life-time extension

In the design of a pipeline, a design lifetime is established. Usually this is thirty (30) years. When this lifetime has expired, a proof of fitness for use is required. This means that an extensive program is required to keep the pipeline in operation. All kinds of inspections (sample points, intelligent pigging, radiographic, ultrasonic, Rontgen) can be used to establish a proof of fitness for use.

D. Abandonment

When a well is fully completed, the infrastructure needs to be abandoned. A program starts to clean the pipeline. Tests must establish that the content of contaminators in the pipeline is below a threshold level. The pipeline gets flooded with water, and when appropriate decommissioned. The actual removal of a pipeline is obliged by regulations, however an extension can be given by the authorities for the period that the pipeline is allowed to remain in place.

2.3. SDI Components

By creating an information infrastructure as the nerve system of the company, data and information will be available throughout the organization. This results in a single data source, no duplication, no different versions – everybody in the company is actually talking about the same thing.

Separate, independent systems that now use their own data, could get linked to the same data resources all over the company. Data has to be stored only once, most favorable by the people who work most with the data. This can be done in the same way it has already been done, except that by agreeing on the standards and policies, this data gets accessible throughout the company. In case the same kind of data is already used by different users in different structures and data sets, the benefit is even greater, if the agreement does not compromise existing functionality.

To demonstrate this principle and as proof of the concept, this research highlights one aspect of the company's business: pipeline integrity management. The full benefit of a companywide infrastructure will only be reached if also other aspects of the company get connected. It is hoped that through this research, implementation throughout the company will get attention. Recognition of the importance of good access to data should result in integration of the SDI in the company's management system.

As already introduced in section 1.3, the hypothesis of this research is that a SDI is suited as a solution to the data and information management issues at the company. A SDI be seen as the result of the interworking of various components (see (Rajabifard, 2008, p. 13)):

A. Standards
B. Data
C. People
D. Policy
E. Access network

This thesis research focusses mostly on the first two components, however, in this section also the other components are briefly described in relation to the particular corporate environment of offshore pipeline integrity management. This section describes which components are present at the company.

A. Standards

One of the main foundations of a SDI is standardization. If data is to be reused by different applications and parties, methods to access the data through services must be implemented that can recognize the existing data structure, know what data structure is required and how to manipulate (harmonize) the actual data to deliver it in the required structure. Data standards are essential to make the functionality of these services possible. Furthermore, standards for the services and the portrayal of the data exist. This research focusses on the data standards.

For the company, by implementing and adhering to international data standards, an openness and future relations with the 'outside world' can be established. Making use of existing data outside of the company is made easier and exchanging data from the company with outside parties is formalized. Company can suffice with explaining which data standards are used, and other parties can deal with the data in their own way.

For pipeline and seabed data several industry standards exist. Also national, European and international data standards can apply – both domain specific (i.e. pipelines, seabed, and permits) and general geographical information standards. The standards that are applicable in the context this research are (in alphabetical order):

- IMKL (Informatie Model Kabels en Leidingen)
- INSPIRE directive (General model and application schemas)
- ISO/TC 211, 19100 series (geographical information and services)
- ISO 19152 Land Administration Domain models (permits)
- ISO 15926 (Process plants)
- NEN 3610, IMGeo
- Pipeline_ML (OGC)
- PODS (Pipeline Open Data Standard)
- SSDM (Seabed Survey Data Model)

Some of these standards are slowly getting acceptance in the domain of E&P companies and new applications might be based on these standards. The various standards are given more attention in section 5.2. Figure 6 shows a proposed hierarchy of standards, based on the identified standards and the relation with the research context.

A company geographic data infrastructure is the context for the application of the standards. In this infrastructure, a company data model defines all related data. Part of the company data model is the pipeline integrity data model. This date model is related to (inter)national standards for geographical information on the one hand, and industry standards on the other.

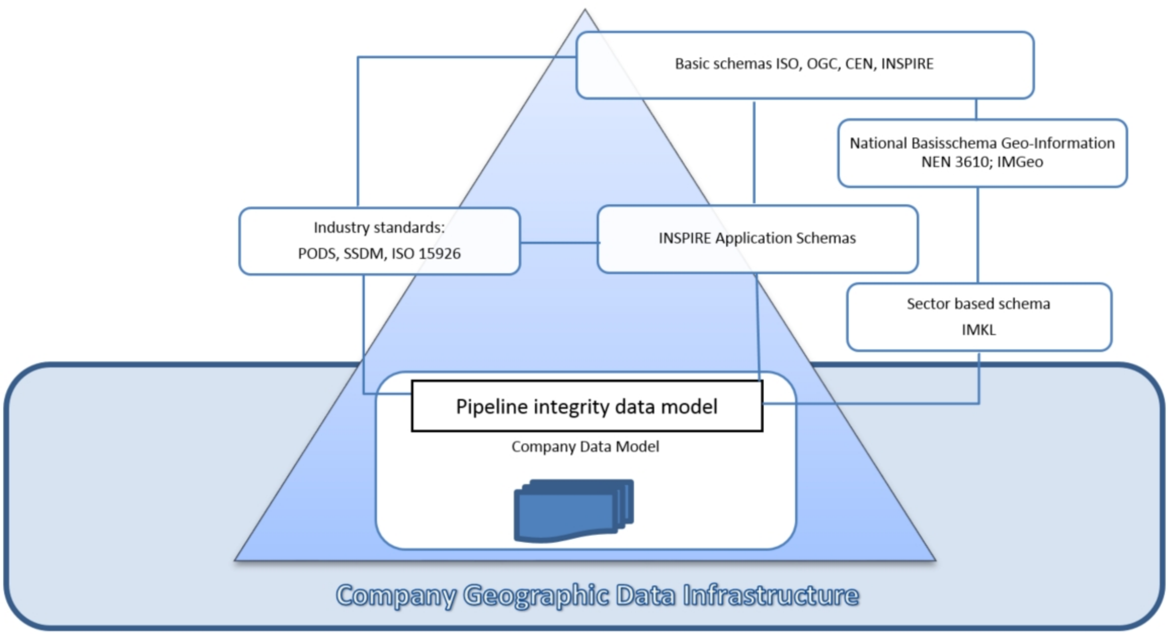


Figure 6: hierarchy of standards

During the research is has become clear that the relation between the industry standards and the (inter)national geographical information standards is not formalized yet. Awareness of the relevance of this relation might not yet exist at the organizations that deal with the industry standards. The drive for these standards has always been real-world applications. The more abstract and formal definition of the (inter)national geographical standards has not yet reached the level of the industry standards. It is expected this will happen in the future. This research hopes to contribute to the integration of the different standards.

On two levels a gap is identified:

1. Basic schemas for geographical information as defined in the ISO 19100 series are not used by the PODS, SSDM and ISO 15926 data standards. They have their own methods to describe the geometric properties of the data.

2. Some of the different standards relate to the same objects, but are not related to each other. For example, the INSPIRE application schema for Utility Networks defines how pipeline networks could be modeled. The same does PODS. However, they don't share any attributes. Model to model mapping is required to come to a common ground.

Other standards

Other standards that are applicable to the research context have been omitted from Figure 6 and the rest of this thesis research, where they are not specifically related to data management. This refers mostly to pipeline integrity management standards.

A lot of industry standards exist for pipeline integrity management. These standards generally prescribe the inspection methods, functional requirements and management processes involved in pipeline integrity management. The main standards the company use are:

- **NEN 3650 series**; pipelines, specifically NEN 3656, offshore pipelines (in development)
- **prEN 16348**; Gas infrastructure – Safety Management System (SMS) for gas transmission infrastructure and Pipeline Integrity Management System (PIMS) for gas transmission pipelines – Functional requirements
- **ISO 19345**; Offshore Pipeline Integrity Management, in progress
- **ASME B31 8S**; Managing System Integrity of Gas Pipelines
- **DNV-RP-F116**; Integrity Management of Submarine Pipeline Systems

These standards hardly mention data and information management. For the development of the SDI, these standards are therefore not particularly useful. If the standards require specific data, pipeline integrity engineers who work with the standards should define the data requirements, based on existing data standards.

One specific standard that is focused on the integration of life-cycle data of a related domain is: **ISO 15926**; Industrial Automation Systems and Integration: Integration of Life-cycle Data for Process Plants, Including Oil and Gas Production Facilities). This standard is studied more in depth in 0.

B. Data

The data considered in this research is data required for pipeline integrity management. In this section the data is briefly described. In section 3.3 the used data is thoroughly documented. Three data sources have been selected (with the location where the data is kept):

1. Offshore pipeline centreline geometry (pipelines group)
2. Seabed survey data (survey group)
3. Permit information (legal department)

Other data sources that have been considered are:

- Production data (volumes, pressures, compositions, inhibitor injection etc.)
- SCADA data
- Visual pipeline inspection data (ROV, Dive)
- Maintenance data
- Legal data (Proximity/crossing agreements)
- Other survey data: Pipeline route survey (Geotechnical data, Pipeline pre-lay survey, Pipeline as-built survey)

All data used in the company's systems use the following coordinate reference systems unless specified otherwise:

- Horizontal spatial reference system of x and y coordinate control points is ED50, UTM zone 31 N, Eastings and Northings in [m]
- Vertical reference system is LAT [m]
- For pipeline linear referencing, M values are expressed in [m] along the pipeline route

For more information about the geometric parameters, see Annex VI.

B.1. Offshore pipeline centerline geometry

The pipelines considered for this research are all offshore pipelines. The pipelines of company's network needs to be modeled based on its geometric properties (its location relative to the earths' surface), its thematic semantic information (information about the physical or administrative properties of the pipeline) and the moment in time in which specific data is applicable, to enable the storage of all the data required at each specific life-cycle stage. In section 0, the modeling process will be described in more detail. The modeled pipeline is called the pipeline centerline.

As the company's networks are not only made up of pipelines, but also consists of wells, platforms, modules etc, company has defined in the GOIMS standards what part of the network falls under the regime of the PIMS. The pipeline limit is as indicated in Figure 7. This typically applies to the pipeline sections on platforms. Platforms fall under the regime of SIMS ('PSIMS' in the figure).

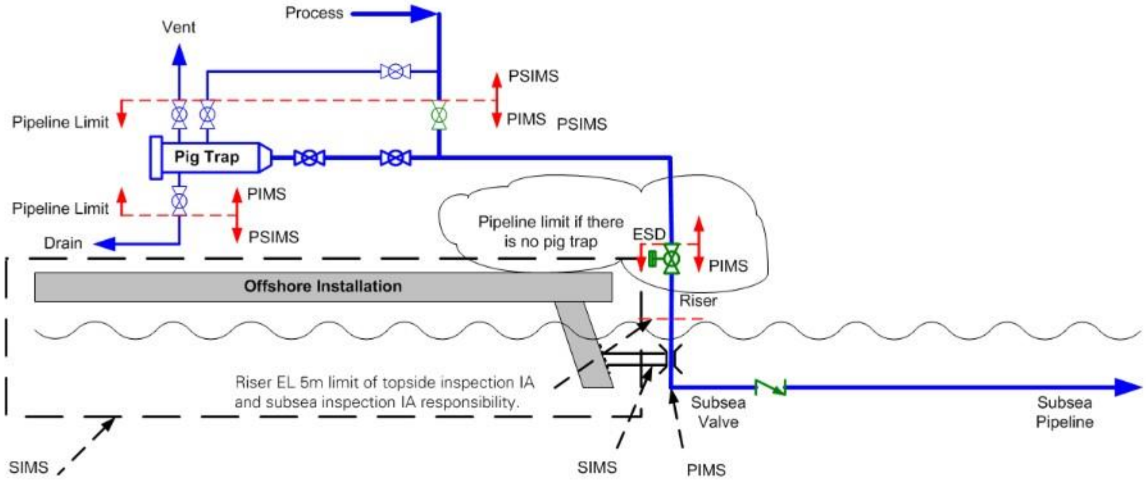


Figure 7: Pipeline limit; taken from (GDF SUEZ, 2012)

According to GOIMS a pipeline must be a containable system. Isolation of the pipeline must in any case be possible. If a pig trap (launcher or receiver) is installed, the pipeline falls under the regime of PIMS up to the pig trap, including every first valve of every side branch on the pipeline. If no pig trap is installed, the first ESD (Emergency Shut-Down Valve) is the end (or start) of the pipeline.

All kinds of properties, characteristics, events and objects can be related to the pipeline centerline. The method the company is currently implementing for relating features to the pipeline centerline is linear referencing. In this method, the geometric properties of the pipeline are expressed by the centerline. This centerline consists of x, y and z[2] coordinates in a specified vertical and horizontal reference system, with linear referencing values expressed by either a measure (m), a KP-value (kilometric point), or an engineering station, measuring along the length of the pipeline route.

All pipeline data is currently in the process of being related to the pipeline centreline through the linear referencing system at the company. The pipeline geometry is maintained by the pipelines group.

B.2. Seabed Survey data

One specific kind of data are involved in all life-cycle stages of pipelines: bathymetric data of the seabed along the pipeline routes. This data is the focal point of this research. It describes the elevation of the seabed at a specific place, in a specified vertical and horizontal reference system. For all the pipelines in the company's network, yearly acquisition of the data with multibeam echo sounder systems is performed by a survey company. A vessel equipped with sensors sails along the pipeline route and acquires the data. The data gets processed (tidal corrections, heave compensation, noise filtering etc.) and gridded.

B.3. Permit information

To construct and use a pipeline, a strict regulatory and permitting system exists in the Netherlands. At different moments in time and at different locations, different regulations apply and permits are required: The Dutch Mining Act (Mijnbouwwet), The Dutch Water Act, the MER (Environmental Impact Analysis), WION (Information Exchange Subterranean infrastructures), BEVB (Decree on the external safety of pipelines), Natura 2000 just to name a few.

Burial requirements

The permit for construction and the agreement on operation of the pipeline as stipulated in the Mining Act is taken as an example for the SDI. Typically, part of the permit for construction is an obligation to keep a pipeline buried for a certain depth, if that pipeline is smaller than sixteen (16) inch.

Risk based integrity management and permits

Instead of the same permit requirements for each and every pipeline section, differentiation of the permitting regime based on the environment of the pipeline is proposed. However, it is not clear yet how this differentiation must be formalized. Different conditions to ascertain the amount of risk a certain pipeline section runs, must be combined. Different geographical data sources are involved in this. This could mean a change of survey, inspection and maintenance

[2] Company is currently in the process of defining the z-value of all pipelines.

program for the company. An SDI is exceptionally well equipped to deal with such differentiations.

C. People

The people involved with the data that is required for pipeline integrity management are presented in Table 1. In short, the following people are involved and are included in (part of) the scope of this research[3]:

Actor	Role	Involvement	Internal/external
Authorities	- Issue and control permits - Offer/require data sources	Direct	External
Contracted survey companies	- Execute survey jobs - Acquire, (pre-)process, deliver data	Direct	External
Engineering and construction companies	- Offer/require data sources	Future	External
Legal department	- Request and maintain permits	Indirect	Internal
Maintenance Support & Planner	- Plan and implement inspection and survey program	Indirect	Internal
Marine Surveyor	- Manage survey jobs - Collect, interpret, process and analyse survey data - Centerline defintion	Direct	Internal
Other departments	- Offer/require data sources	Future	Internal
Pipeline Integrity engineer	- Manage inspection jobs - Collect, interpret, process and analyse inspection data - Centerline defintion	Indirect	Internal
Pipeline Systems manager	- Maintain integrity of pipeline network - Request and maintain permits	Indirect	Internal
Specialist researchers	- Offer/require data sources	Future	Internal/External

Table 1: People and their involvement in the research scope

The organizational context of this research is described in Annex I. It deserves highlighting that GIS in an Engineering and Construction department of an Exploration and Production company is usually low key. Most of the spatial analysis happens at the Exploration and Development department for subsoil seismic data.

D. Policy

By agreeing and implementing policies, the institutional context of a SDI gets arranged. This is made concrete with access rights, transaction costs, update policies, etc. Company does not have geographical information data policies at the moment and, in general, GIS awareness is very low. However, a lot of data with a geographic component is already used by various departments. Geo-enabling and integrating this data in a company SDI would bring huge advantages for the company as a whole. Company management should decide on such an investment.

[3] Involvement is meant as follows:
- Direct involvement: currently working with the data or requiring processed data
- Indirect involvement: part of the organizational context
- Future involvement: actors that might get involved with data exchange in a later stage

If they do, policies need to be defined, agreed and implemented. An indicative list of policy issues is provided below in Table 2:

Type	Description
Strategic policy	What, where, when, how, by whom
Implementation policy	Hardware set-up
	Applications & databases set-up
	Connect existing systems and loading data
	Data gaps analysis
Operational policy	Hardware maintenance
	Application & database management
	Roles and rights
	Updates
	Collected, harmonize and integrate additional data
	Payment/costs

Table 2: Company policies for SDI

The GOIMS standard, and more precisely the PIMS standard, is the overall policy for pipeline integrity management. Neither the GOIMS as the PIMS standard mentions geographical information management. Some kind of bridging document between the standards and the policies to be developed for data exchange should be made, to make data exchange part of the groups' standard documents.

Moreover, the company's management system manages all business processes. Every task in the business processes is described, including the data in- and output requirements. Integration of the SDI in this system should be a top priority for the policy requirements.

Policies for exchanging data with external parties do not exist. For data from surveys companies, the deliverables are arranged per contract. After finalizing the work, the data is delivered as download or on DVD. Data for authorities are generated as special outputs in formats specified by the authorities. This happens once a year. Currently no specific demands from the authorities exist to deliver the data as a service.

It would be a huge advantage for the company to be able to access and deliver data via services according to mutually agreed policies with the data providers (i.e. survey companies, engineering and construction companies etc). This thesis research hopes to contribute to a step towards this by a providing a proof of concept.

E. Access Network

During various stages in the life-cycle of a pipeline, data gets exchanged. An access network with ample facilities would be most beneficial for this. As a SDI is flexible in nature, it should be possible to add access services to it at various moments. At those moments, interfaces need to be developed and technology implemented. Currently, no specific access network for a SDI is implemented at the company. The company has ample databases, workstations etc. Data exchange can be arranged through a company FTP-server.

As far as the structure of the data can be regarded as part of the access network, attention is given to this SDI component. Issues pertaining transformation of existing data to interact with other applications and to comply with existing standards, are studied. Chosen is to do manual transformations where necessary.

3. Offshore pipeline integrity management

In the previous chapter the context of the research is described by presenting the company's main development process and the life-cycle of an offshore pipeline. Also the SDI components are identified in the research context. Each stage in the life-cycle has specific data requirements. As the nerve system of the company, a SDI should be able to address all of these data requirements, however, the company has indicated that data management for pipeline integrity management during the maintenance and operations stage is the highest priority for the SDI.

This chapter zooms in on one of the stages of the offshore pipeline life cycle: the operations and maintenance stage. Since the duration of this stage is the longest if all goes well with the pipeline and wells, most of the efforts and, more importantly for the company, all of the profits will come from this stage. During this stage, integrity management is particularly important. Although it also applies to the other stages, most of the data and actual work processes related to integrity management are used and executed during this stage.

In section 3.1 an overview of offshore pipeline integrity management is given. Next the different actors and processes are described in section 3.2 and the involved data is documented in section 3.3. Finally two use cases are described that operationalize the requirements of offshore pipeline integrity management for the proposed SDI (section 3.4).

3.1. Overview

In Figure 8, a Use Case diagram shows the actors and the processes they are involved in offshore pipeline integrity management, as far as it concerns permits, inspection and survey data.

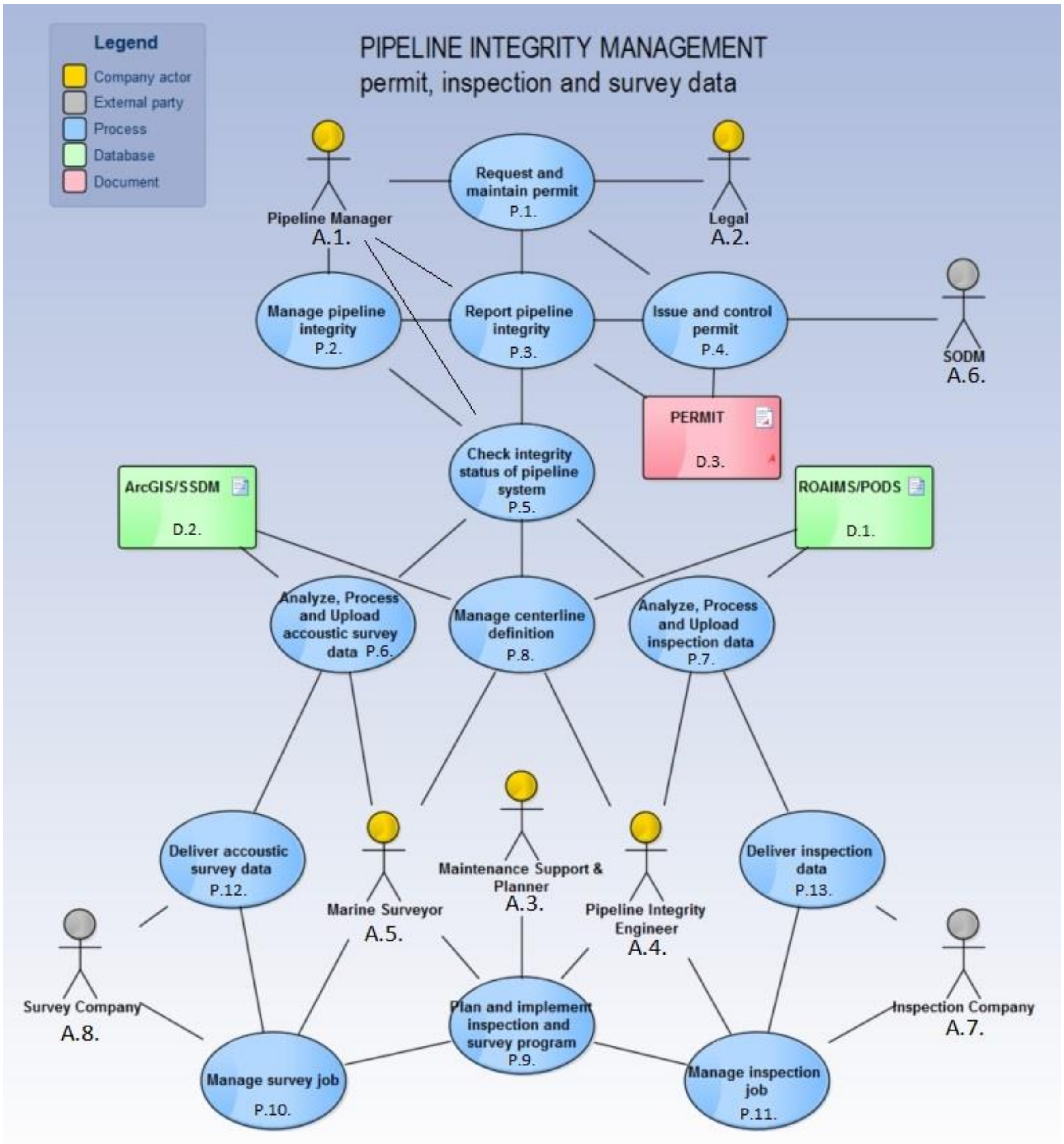


Figure 8: Use Case Pipeline Integrity management - permit, inspection and survey data

Eight (8) actors are identified that are involved in this part of integrity management of pipelines:

A. Company actor
- A.1. Pipeline Manager
- A.2. Legal department
- A.3. Maintenance Support & Planner
- A.4. Pipeline Integrity Engineer
- A.5. Marine Surveyor

A. External party
- A.6. SODM (Staatstoezicht Op De Mijnen)
- A.7. Inspection company
- A.8. Survey Company

Thirteen (13) process are identified that are involved:
- P.1. Request and maintain permit
- P.2. Manage pipeline integrity
- P.3. Report pipeline integrity
- P.4. Issue and control permit
- P.5. Check integrity status of pipeline system
- P.6. Analyze, process and upload acoustic survey data
- P.7. Analyze, process and upload inspection data
- P.8. Manage centerline definition
- P.9. Plan and implement inspection and survey program
- P.10. Manage survey job
- P.11. Manage inspection job
- P.12. Deliver acoustic survey data
- P.13. Deliver inspection data

Three (3) data sources are identified:
- D.1. ROAIMS/PODS (database) – Offshore pipeline centerline geometry
- D.2. ArcGIS/SSDM (database) – Seabed Survey data
- D.3. Permit (document) – Permit information

3.2. Actors and processes

The actors and the processes they are involved in as presented in Figure 8, are described in this section. The role of each actor in offshore pipeline integrity management is mentioned.

A.1. Pipeline Manager

The pipeline manager is responsible for the integrity of the company pipelines. His main task is the implementation and execution of and compliance with company pipeline integrity management standards and systems. For this task he allocates the budget. All communications with the authorities concerning the integrity of the pipeline network should go via the pipeline manager. Within the company, the pipeline manager is part of the management team, giving him the possibility to influence the strategic position of the company. Together with the legal department he manages the regulatory aspects of pipeline integrity management.

The processes the pipeline manager is directly involved in are:

- P.1. Request and maintain permit
- P.2. Manage pipeline integrity
- P.3. Report pipeline integrity
- P.5. Check integrity status of pipeline system

A.2. Legal department

The main task of the legal department with regard to pipeline integrity management, is to maintain all permits for the pipeline network and to advise the pipeline manager with all legal matters, including permits and regulations. The legal department knows exactly which legal conditions apply to the pipeline network and which regulations are relevant for which sections of the pipeline network.

The processes the legal department is directly involved in are:

P.5. Request and maintain permit
P.3. Report pipeline integrity

A.3. Maintenance Support & Planner

The maintenance support & planner works in close concert with the pipeline manager to implement all maintenance matters related to pipeline integrity. Together with the pipeline integrity engineer and the marine surveyor, the maintenance support & planner draft the inspection and survey programs. Job plans are described and the jobs planned. During the executing of the jobs, the maintenance support & planner keeps track of the overall progress.

The process the maintenance support & planner is directly involved in is:

P.9. Plan and implement inspection and survey program

A.4. Pipeline Integrity Engineer

The pipeline integrity engineer is responsible for the execution of the inspection program that is planned together with the maintenance support & planner. All inspection jobs are to be managed by the pipeline integrity engineer in consultation with inspection companies. Inspection data delivered by the inspection companies is to be analyzed, processed, assessed and uploaded to the company's databases. Together with the marine surveyor, the pipeline engineer is responsible for the correct representation of the pipelines in company's databases.

The processes the pipeline integrity engineer is directly involved in are:

P.7. Analyze, process and upload inspection data
P.8. Manage centerline definition
P.9. Plan and implement inspection and survey program
P.11. Manage inspection job

A.5. Marine Surveyor

The marine surveyor is responsible for the execution of the survey program that is planned together with the maintenance support & planner. All survey jobs are to be managed by the marine surveyor in consultation with survey companies. Survey data delivered by the survey companies is to be analyzed, processed, assessed and uploaded to the company's databases. Together with the pipeline integrity engineer, the marine surveyor is responsible for the correct representation of the pipelines in company's databases. The marine further prepares the reporting to SODM (Staatstoezicht op de mijnen).

The processes the marine surveyor is directly involved in are:

P.6. Analyze, process and upload acoustic survey data
P.8. Manage centerline definition
P.9. Plan and implement inspection and survey program
P.10. Manage survey job

A.6. SODM (Staatstoezicht Op De Mijnen)

The SODM is the authority that controls the compliance with the Dutch mining act. Every mining company that operates on the Netherlands territory or Dutch Exclusive Economic Zone (including territorial waters) is obliged to report to the SODM. The status of mining installations and the pipeline network plus the assessment and work program for non-conformities is to be reported by the mining company.

The process SODM (Staatstoezicht Op De Mijnen) is directly involved in is:

P.4. Issue and control permit

A.7. Inspection Company

The inspection company is contracted by company to perform explicitly described inspection jobs. Together with the Pipeline Integrity Engineer the inspection job is managed. The inspection company delivers the data to the Pipeline Integrity Engineer as specified in the inspection program.

The process the inspection company is directly involved in is:

P.10. Manage survey job
P.13. Deliver inspection data

A.8. Survey Company

The survey company is contracted by company to perform explicitly described survey jobs. Together with the Marine Surveyor the survey job is managed. The survey company delivers the data to the Marine surveyor as specified in the survey program.

The process the survey company is directly involved in is:

P.10. Manage survey job
P.12. Deliver acoustic survey data

3.3. Data

In section 2.3, three data sources are identified at three different parts of the organization: **Offshore pipeline centerline geometry** at the pipelines group, **Seabed data** at the survey group and **permits** at the legal department. These three sources are to be combined by the SDI. In this section, the three data sources are described and documented. This is the as-is situation in the company. Chapter

D.1. Offshore pipeline centerline geometry

In 2009, an intensive integrity management project for the company's pipeline network has started. The project is still ongoing and consists (among other elements) of:

- Development of an integrity management pipeline system (IMPS)
- Creation of a pipeline integrity management handbook
- Formalizing maintenance planning and control (including a KPI system)
- Risk and quality management
- Development of an asset management system

The development of the asset management system. This element consists of two parts:

- Software & database implementation
- Data gathering & loading
    - 3D Centerline creation
    - Asset data entry

Rosen ROAIMS for Pipelines software is implemented for pipeline data management and analysis. The software is based on inline inspection tools for aligning acquired intelligent inspection data (see section 2.2).[4] Additions to the software has upgraded it into a full asset management system. Not only inline inspection data but also other kinds of data related to the pipeline assets can be handled by the software. Figure 9 shows the home screen of the software application.

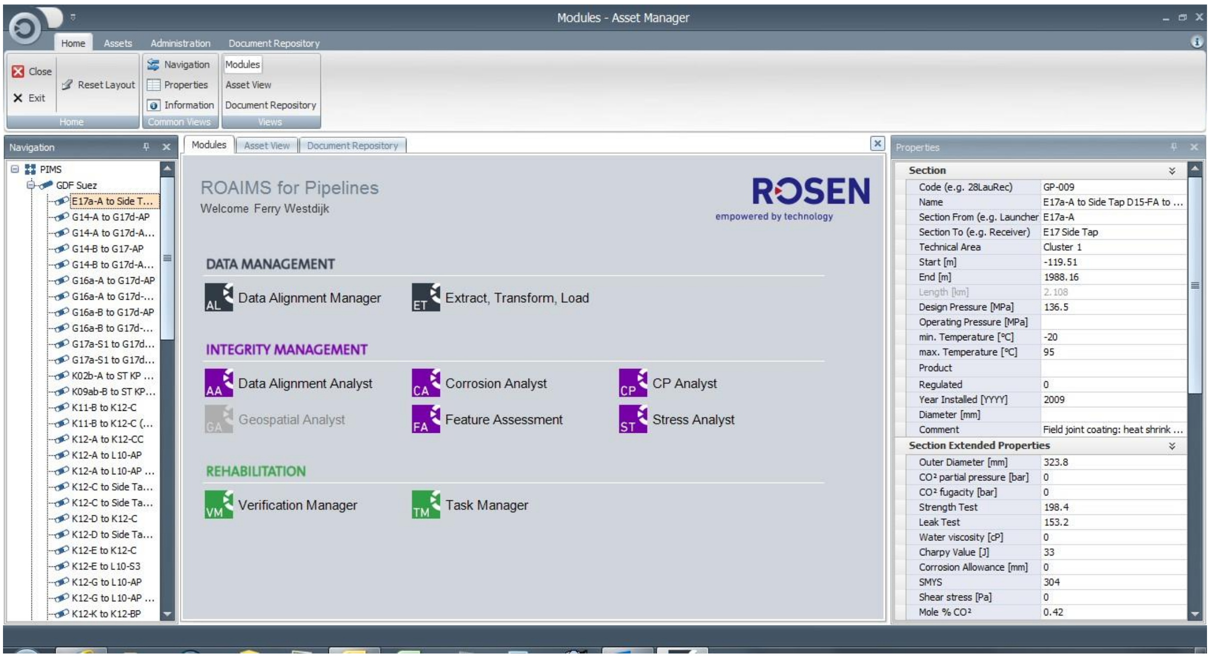


Figure 9: Rosen ROAIMS for Pipelines Asset Manager

The data the software works with is stored in a database on a company MS SQL server 2012. The data model of this database is based on the PODS standard (Pipeline Open Data Standard), see section 5.2 for more information about the PODS standard.

Data gathering, creation of 3D centerlines and quality of data

The second part of the development of the asset management system consists of data gathering, centerline definition and data loading. This is related to work process 8 of the presented pipeline integrity management processes. Both the Marine Surveyor as well as the Pipeline Integrity Engineer is involved in this work process. See Figure 10 for an overview of the workflow.

[4] By running a sophisticated tool with sensors through the pipeline, features like coating damage, pitting and corrosion can be identified. Rosen software can load, align and analyze the inline inspection data.

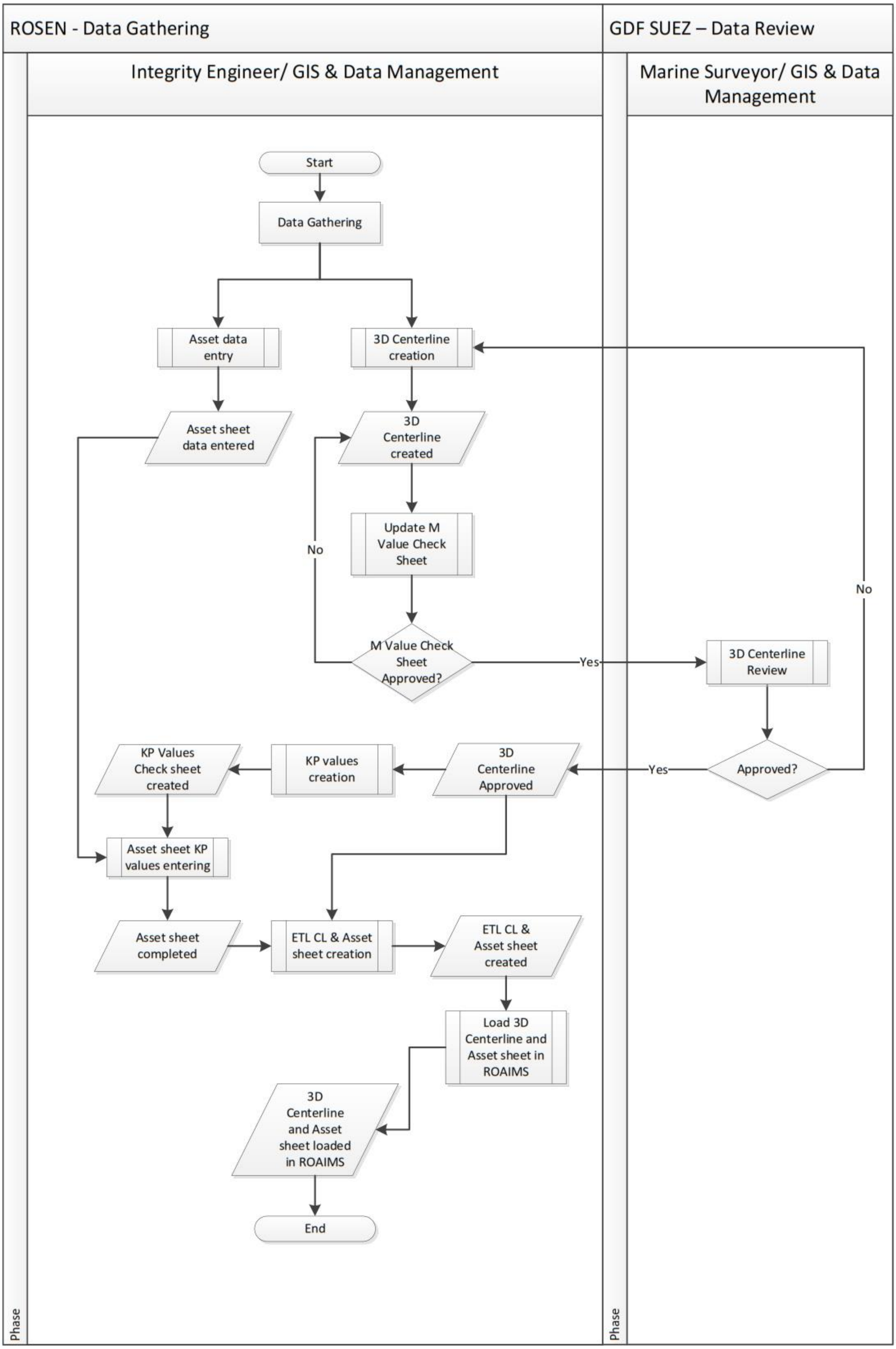


Figure 10: Data gathering and 3D centerline creation workflow; from internal document

This workflow results in loaded data in the actual company PODS database. Two main flows are combined: Asset data entry and 3D Centerline creation.

Asset data is gathered by the pipeline integrity engineer in asset data sheets based on information from pipeline design reports, as-built reports, inspection data, photographs and verbal confirmations of eye-witnesses. As a lot of the company's pipelines are quite old (starting 1974), not all – or sometimes hardly any – data is easily found. Next, reference values for the linear referencing system will have to be taken from the 3D centerline to establish correct the linear referencing values in the asset sheets. The process of filling the asset sheets and applying the correct linear referencing value for the assets has proven to be a very intensive one with major variations in data availablity. As a result, the quality of the data can vary widely.

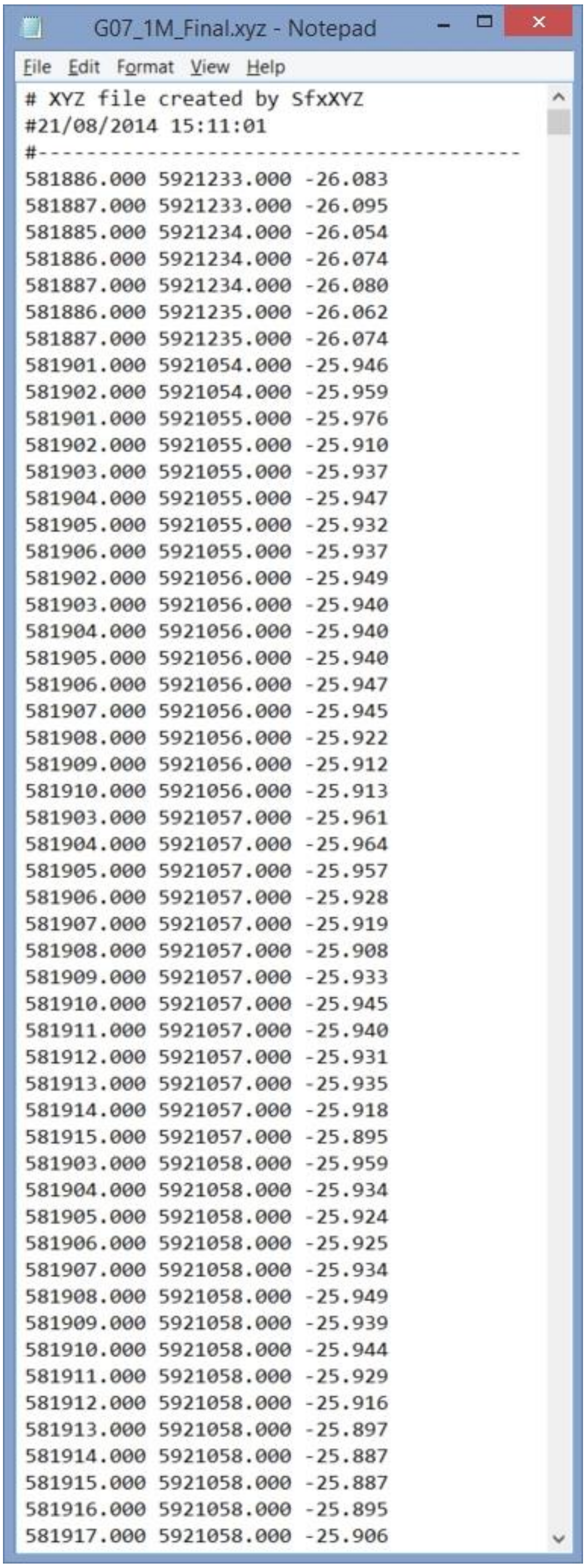
The same can be said of the second workflow: 3D centerline creation. For new pipelines this workflow is quite simple, but for old pipelines it is quite complicated. As source for most of the centerlines old microstation .dgn files and .xls sheets containing Eastings, Northings and KP-measures (Kilometric Point, as measured along the line, generally in the direction of the flow of products) are used. It is hardly known where and how these files were generated, with what quality control, by whom etc. These considerations make it very hard to state anything about data quality, except that it is questionable. Some of the data is probably taken from design data (see section 2.2), some from as-built data during construction (see section 2.2). Also data manipulations may have been performed. It is a known fact that many of the pipeline routes have been adjusted and updated by a Survey Company during Operations & Maintenance (see section 2.2), based on as-found positions as positioning systems and pipeline detection equipment got more accurate through time.

Nevertheless, the selected data is used for the 3D centerline creation process. Reporting on the pipelines this data represents has always used the KP-measures as defined. So these positions and measures are a historically consistent source. Up till now, there has not been a good system in place to control these data quality and lineage issues. Starting with the use of PODS and the 3D centerline creation workflow, this has improved drastically.

For a full description of the 3D centerline creation workflow, see Annex IV.

D.2. Bathymetry data

From 2009 onwards, the survey group at the company has stated in its survey program the requirement for the delivery of multibeam echo sounder data for a defined swath over all of the pipelines – each pipeline has to be surveyed every year. This data is acquired by sailing a vessel with multibeam equipment (transducers) along the pipeline routes. Point cloud data is recorded and after processing (tide reduction, heave compensation, filtering, gridding), x, y and z data including timestamps is recorded. See Figure 11 for an example of the processed and gridded xyz data.



G07_1M_Final.xyz - Notepad
File Edit Format View Help

```
# XYZ file created by SfxXYZ
#21/08/2014 15:11:01
#-----------------------------------------
581886.000 5921233.000 -26.083
581887.000 5921233.000 -26.095
581885.000 5921234.000 -26.054
581886.000 5921234.000 -26.074
581887.000 5921234.000 -26.080
581886.000 5921235.000 -26.062
581887.000 5921235.000 -26.074
581901.000 5921054.000 -25.946
581902.000 5921054.000 -25.959
581901.000 5921055.000 -25.976
581902.000 5921055.000 -25.910
581903.000 5921055.000 -25.937
581904.000 5921055.000 -25.947
581905.000 5921055.000 -25.932
581906.000 5921055.000 -25.937
581902.000 5921056.000 -25.949
581903.000 5921056.000 -25.940
581904.000 5921056.000 -25.940
581905.000 5921056.000 -25.940
581906.000 5921056.000 -25.947
581907.000 5921056.000 -25.945
581908.000 5921056.000 -25.922
581909.000 5921056.000 -25.912
581910.000 5921056.000 -25.913
581903.000 5921057.000 -25.961
581904.000 5921057.000 -25.964
581905.000 5921057.000 -25.957
581906.000 5921057.000 -25.928
581907.000 5921057.000 -25.919
581908.000 5921057.000 -25.908
581909.000 5921057.000 -25.933
581910.000 5921057.000 -25.945
581911.000 5921057.000 -25.940
581912.000 5921057.000 -25.931
581913.000 5921057.000 -25.935
581914.000 5921057.000 -25.918
581915.000 5921057.000 -25.895
581903.000 5921058.000 -25.959
581904.000 5921058.000 -25.934
581905.000 5921058.000 -25.924
581906.000 5921058.000 -25.925
581907.000 5921058.000 -25.934
581908.000 5921058.000 -25.949
581909.000 5921058.000 -25.939
581910.000 5921058.000 -25.944
581911.000 5921058.000 -25.929
581912.000 5921058.000 -25.916
581913.000 5921058.000 -25.897
581914.000 5921058.000 -25.887
581915.000 5921058.000 -25.887
581916.000 5921058.000 -25.895
581917.000 5921058.000 -25.906
```

Figure 11: Bathymetry gridded xyz file

ESRI raster dataset/raster catalogues

This xyz data is gridded with a bin size of one meter and rasterized by the survey company in a raster resolution of one meter horizontal. The raster cell values representing the water depth are digitized in meters, resolution is millimeter (0.001 m). The result is a curved raster per pipeline with a swath of approximately thirty-five (35) meters on both sides of the pipeline route. All rasters of a single survey campaign are collected by the survey group of the company and stored in ESRI raster catalogues. For 2013 and 2014 the raster data is available.

Figure 12 shows the input curved raster datasets in an ESRI file geodatabase. This specific data is from the survey campaign of 2013. For each pipeline a curved raster is stored and for each raster.

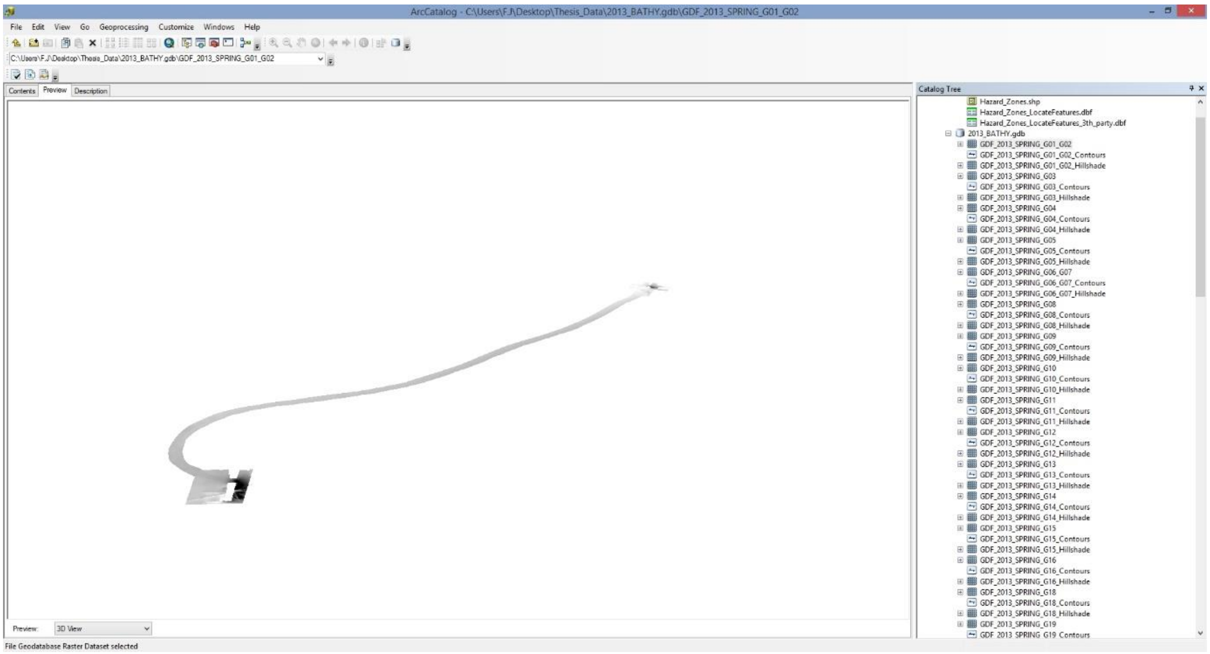


Figure 12: Bathymetry data in ESRI file geodatabase

Next, the rasters are combined in a ESRI raster catalogue, see Figure 13 for an overview of the bounding boxes of the raster catalogue.

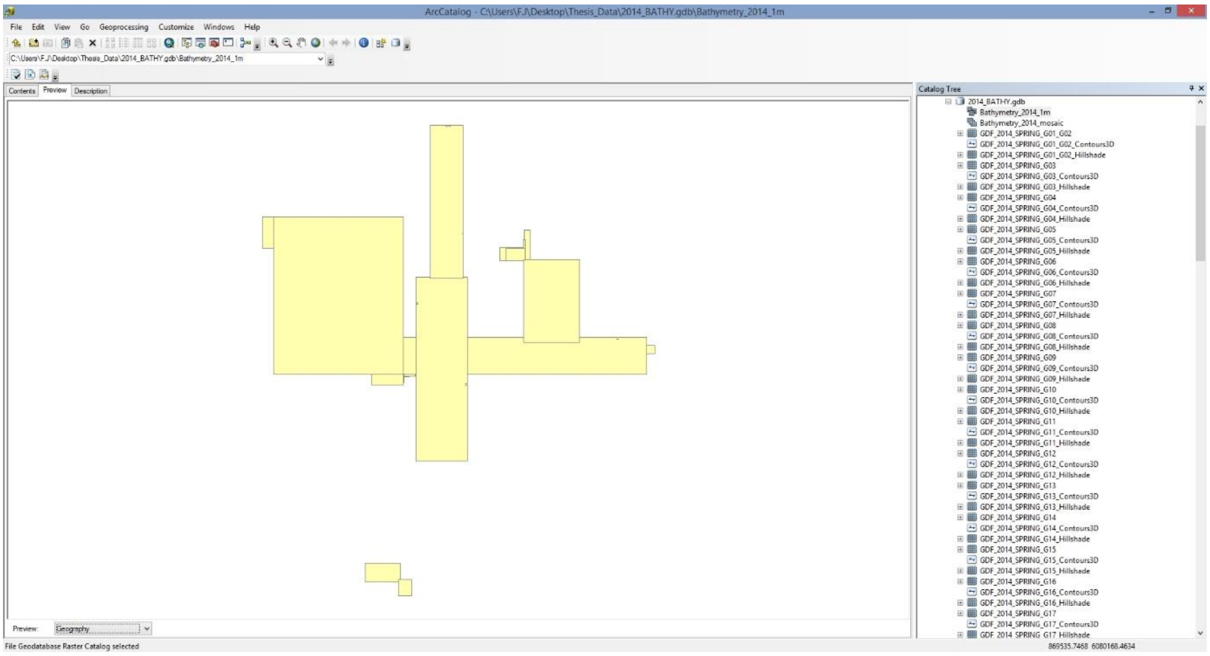


Figure 13: Bathymetry in an ESRI raster catalogue – bounding boxes

Generally the rasters in the ESRI file geodatabase are used for analysis, the ESRI raster catalogue for quick viewing.

SSDM

Since 2013 company has started a pilot with the survey company to standardize the data deliverables. The internationally developed SSDM (Seabed Survey Data Model) is chosen as standard. A first test was done and the results looked promising. Currently company is preparing to change the data requirements in the survey agreements for the next survey campaigns (2016 onwards). See Figure 14 for the deliverables of the test.

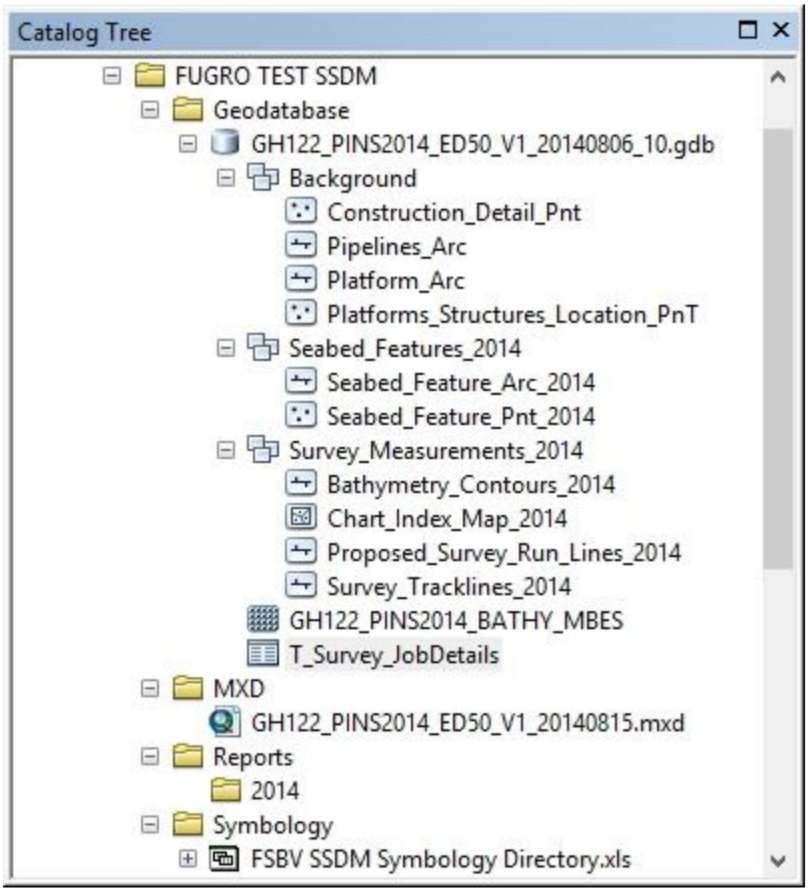


Figure 14: Test SSDM

As this was a first test, data for only one pipeline was included in this deliverable. Company is now defining deliverable requirements.

The SSDM is developed as an exchange method. For a new survey job, company should fill a SSDM template database with relevant data and hand the database over to the survey company. After the survey job is performed by the survey, the acquired data and metadata is loaded in the geodatabase by the survey company. The whole geodatabase is delivered to the company, where the master SSDM database is appended with the new data.

D.3. Permit information

Actual permit information is scarce. When requested by the pipeline manager, the legal department could only provide an overview checklist for regulations applying to the construction of new pipelines. No actual data is present, except for .pdf files of permits for construction and fitness for use certificates. However, these are not centrally stored or directly accessible. It is highly recommended that the pipelines group organizes these documents in a document repository system.

Burial requirements

In these documents the conditions are formulated with which a pipeline must comply. For this research only the burial conditions are of interest. As there is no variation for this condition (i.e. either a pipeline must be buried to a minimal depth of fifty (50) centimeters or not), a simple table is created in the survey groups geodatabases, to contain this requirement per pipeline. A buffer around each pipeline is created (twenty-five (25) meters at both sides of the pipeline)

For convenience, the data has been loaded in an ESRI geodatabase polygon feature class with the following fields:

- FID (ObjectID)
- SHAPE (Geometry)
- ISSUED_BY (Text)
- DATE_ISSUED (Date)
- LINE_GUID (Text)
- ROUTE_GUID (Text)
- VALID_FROM (Date)
- VALID_TO (Date)
- CREATED (Date)
- CONDITION_OPERATION_PRESSURE (Integer)
- CONDITION_BURIAL_DEPTH (Double)

The Geodatabase feature class contains 90 features. See Figure 15 for an overview of the geometry of the features.

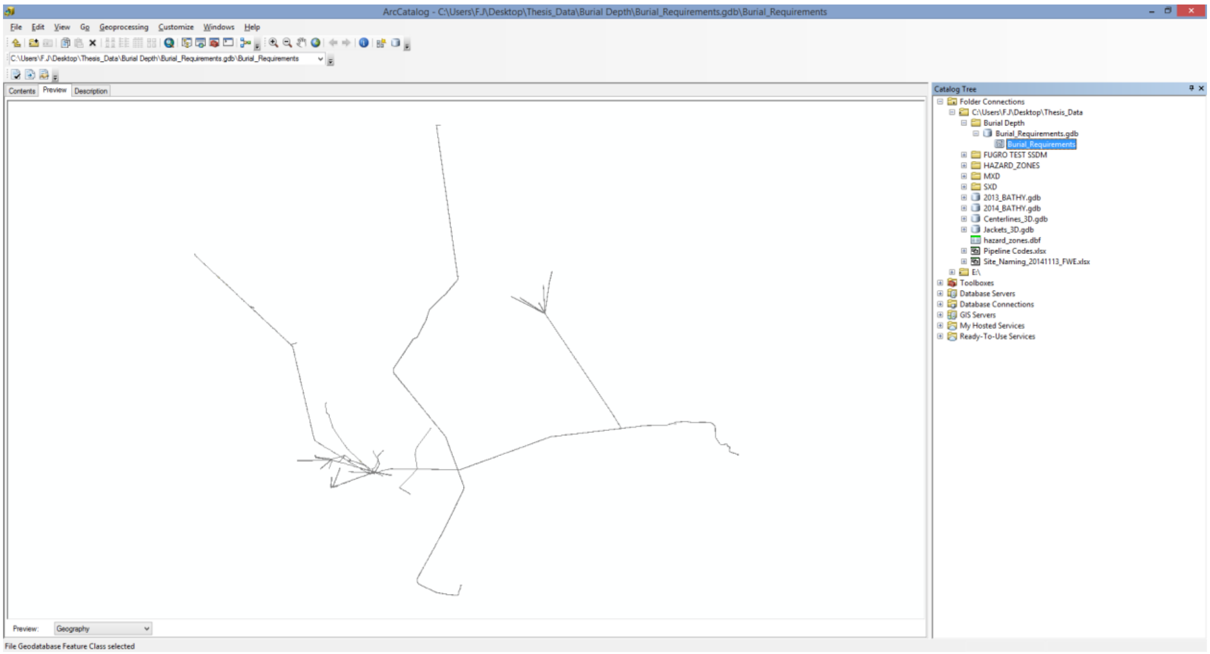


Figure 15: Burial requirements feature class

Risk based integrity management

As indicated in section 2.3, an expected development in the field of pipeline integrity regulations is Risk based integrity management and permits. Instead of the same permit requirements for each and every pipeline section, differentiation of the permitting regime based on the environment of the pipeline is proposed.

Data related to regulations and restrictions on the North-Sea that can be related to the risk profile of certain locations has been inventoried. Data from the following organizations has been identified as relevant:

- Hydrographical services
- Rijkswaterstaat
- Interwad

The data contains information about

- Shipping (Shipping lanes, anchoring and harbor approach zones)
- Military areas
- Natural preservation areas (Natura 2000, Art. 20, Special ecological value)
- Windfarms
- Sand suppletion areas
- Dump areas
- Political/administrative areas

For convenience, the data has been appended in an ESRI polygon shapefile with the following fields:

- FID (ObjectID)
- SHAPE (Geometry)
- NAAM (Text)
- ACCESSIBIL (Text)
- SOURCE (Text)
- SHAPE_Leng (Double)
- SHAPE_Area (Double)
- NAME (Text)
- TYPE (Text)
- TYPEGEBIED (Text)
- NAAMGEBIED (Text)
- BEHEERDER (Text)
- LAST_UPDAT (Date)
- ID (Short Integer)

The shapefile contains 3609 features. See Figure 16 for an overview of the geometry of the features.

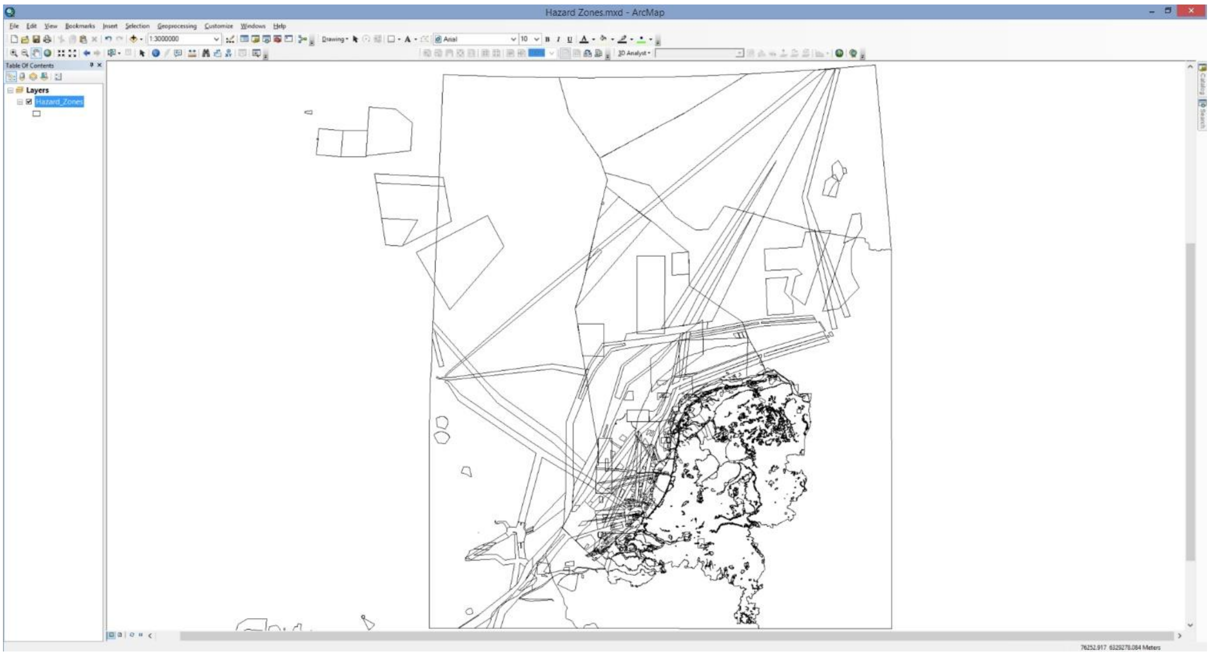


Figure 16: Permits shapefile

3.4. Two use cases for pipeline integrity management

To demonstrate the concept of a SDI, two use case are defined to test the prototype. These use cases are based on actual work processes that are part of the company's pipeline integrity management. In this section the two use cases are presented. In section 6.2 the prototype SDI is actually tested by these use cases.

Pipeline burial and external threat

Both use cases deal the same issue: pipeline burial and external threat. The overall concept is that when an offshore pipeline is not buried, a risk exits that compromises the safety. Pipeline burial conditions are stated in the permits to control this threat and also from the offshore pipeline integrity perspective this is an unwanted situation. The risks that have been identified by company related to this issue are categorized as 'external threat'. This can be understood in two ways:

1. External forces can do harm to our pipelines; for example: an exposed pipeline can be damaged by fishing activities by dragging fishing gear or by dragging anchors.
2. Our pipeline can do harm to the environment; for example: leakages, ruptures, releases of content. But also fishing activities might be threatened: when fishing gear gets stuck behind a pipeline, the fishing vessel might get damaged.

Figure 17 shows a use case diagram that describes involved actors, processes and data resources for pipeline burial issues.

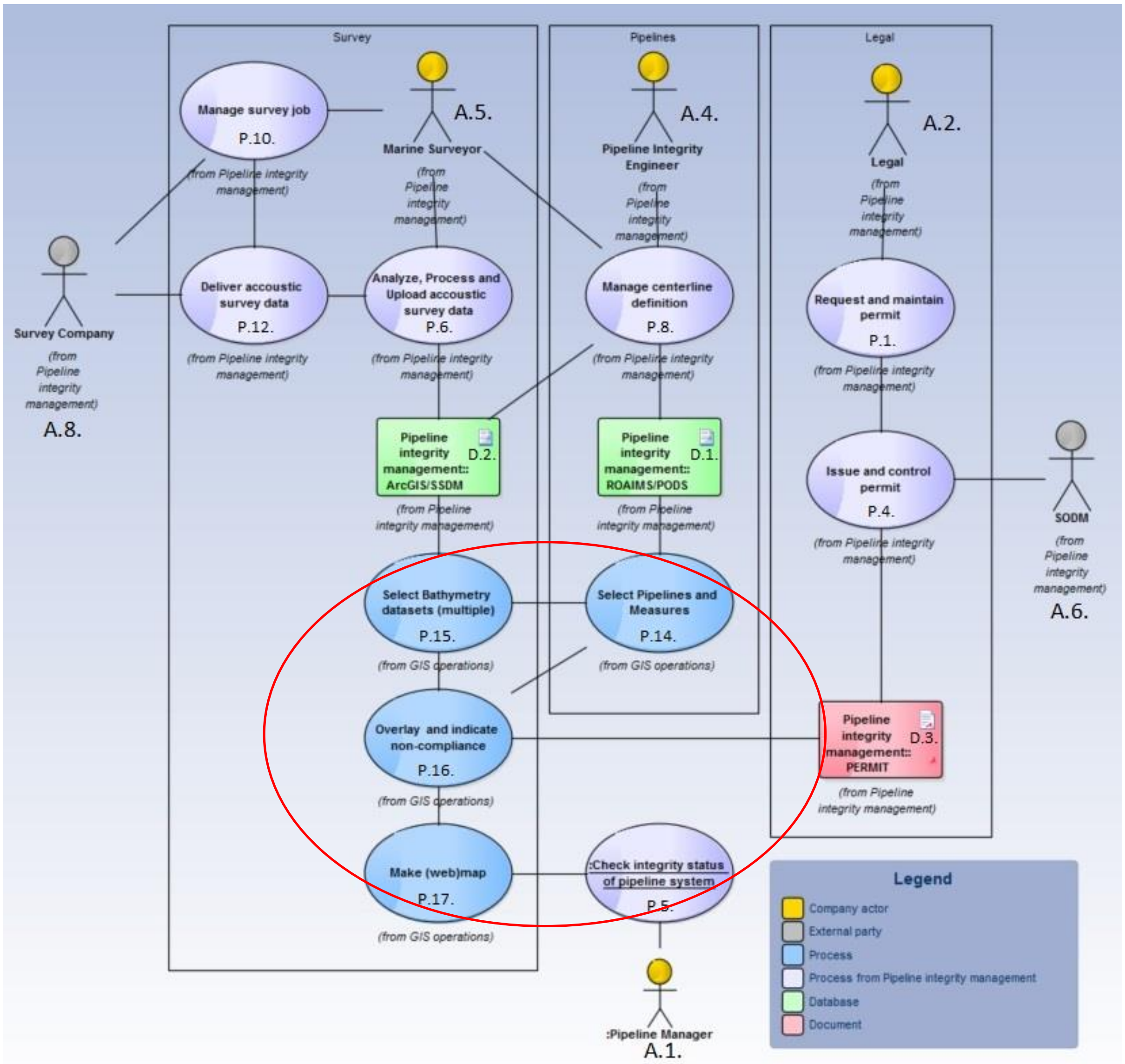


Figure 17: Use case diagram for pipeline burial issues

Many of the involved processes are already part of the overall pipeline integrity management workflow. Only a couple of steps are added:

- P.14. Select pipelines and measures
- P.15. Select Bathymetry datasets (multiple)
- P.16. Overlay and indicate non-compliance
- P.17. Make webmap

Also an implementation of the process of the Pipeline manager is included:

- P.5. Check integrity status of pipeline system

For both of the use cases these steps are required. How the steps are performed, however, differs per use case.

Per use case is described how in reality the steps would have to be performed.

Use case 1: monitor dynamic seabed conditions at known locations

The first use case must demonstrate the SDI's capability to serve bathymetric raster datasets of different periods in the same area including the 3D pipeline position.

For some locations it is known from history that seabed conditions change rapidly. This poses a threat to the pipeline integrity and can result in a non-conformity with respect to pipeline burial requirements.

Processes/steps use case 1

P.14. The Pipeline Engineer (A.4.) indicates that on a certain pipeline sections, dynamic conditions can be expected – based on his ROAIMS systems data. He thinks the sections should be checked and informs the Marine Surveyor about the sections. His message may look like:

<Pipeline Code GP-001, KP 6.580 to KP 6.620, dynamic seabed?>

P.15. The Marine Surveyor (A.5.) selects the bathymetry datasets available for this pipeline section from the Survey Groups ArcGIS/SSDM geodatabase. Also he loads the offshore pipeline geometry from the Pipeline Groups ROAIMS/PODS database and the Permit burial conditions from the Legal departments tables.

P.16. The Marine Surveyor overlays the different bathymetry raster sets with the 3D pipeline and zooms to the indicated section. By turning on bathymetry layers from different dates, he can judge whether or not dynamic seabed conditions might compromise the pipeline integrity. Also he can check what the burial requirements are for this pipeline section.

P.17. If the interpretation of the data leads to the conclusion that the pipelines' integrity might be compromised, the Marine Surveyor can generate a (web)map that shows the situation of the seabed conditions. On this map would be two or three images next to each other to indicate what the seabed looks like at the different moments, including the time (year) of acquisition, with the pipeline indicated on it. Additionally cross- and longitudinal profiles can be added over or along the pipeline route.

By executing the described steps, the pipeline manager should easily be informed on the status of known trouble areas.

Use case 2: find non-complying pipeline sections

The second use case must demonstrate the SDI's capability to perform analyses on the most recent bathymetric data to come to a list of non-confirming pipeline sections. These are generally exposed and free spanning pipeline sections.

Refer again to Figure 17. The processes and steps involved in this use case are presented below:

Processes/steps use case 2

P.14. The Pipeline Engineer (A.4.) requires to update his ROAIMS systems data for Pipeline GP-001. He informs the Marine Surveyor about this. His message may look like:

<Pipeline Code GP-001, non-compliance?>

P.15. The Marine Surveyor (A.5.) selects the most recent bathymetry dataset available for this pipeline section from the Survey Groups ArcGIS/SSDM geodatabase. Also he loads the offshore pipeline geometry from the Pipeline Groups ROAIMS/PODS database and the Permit burial conditions from the Legal departments' tables.

P.16. The Marine Surveyor overlays the bathymetry raster set with the 3D pipeline. By performing an interpolation of the 3D centerline over the bathymetry raster set, he derives a longitudinal profile over the pipeline route. This longitudinal profile can be compared with the profile of the 3D centerline itself and a profile indicating the burial requirements is added. Simple mathematics should result in a list of pipeline sections that are non-complying.

P.17. If the interpretation of the data leads to the conclusion that the pipelines' integrity might be compromised, the Marine Surveyor can generate a (web)map that shows the overview of the non-complying pipeline sections. On this map would be an overview of the complete pipeline route, with the non-complying sections indicated with symbols and annotation like "KP 6.580 – KP 6.620". Also the generated longitudinal profiles of the non-complying sections could be added to this map.

An additional use case: Risk based integrity management

The second use case can be extended by using different permit requirements. As discussed in sections 2.3 and 3.3, a future development is risk bases integrity management. By using the described Hazard Zone data source for defining sections of the pipeline that require different standards, the permit and the inspection and survey program might be renewed.

A linear referencing overlay operation can combine the centerline geometry data with the identified Hazard Zones. A resulting table containing sections with specific requirements can then be added to the map as created for the second use case.

In section 6.2 these use cases are tested with live data to assess the capabilities of the proposed SDI. The next chapter describes in depth the rationale of SDI's.

4. Corporate SDI - Interoperability at the corporate level

This chapter is meant to provide an overview of existing solutions for making systems and data interoperable. Ways to reuse and exchange data are explored by browsing through recent technological developments. The problem definition of this research is recapped in section 4.1, while section 4.2 supports the choice for a SDI in this research context. A dimension is added in section 4.3, when SDI and Enterprise Architecture are related. Section 4.4 deals with the common denominator of both approaches: interoperability. Finally, in section 4.5 semantic interoperability is identified as a key concept for this research.

4.1. Multi-view information infrastructure

A starting point of this thesis is that a multi-view perspective on pipeline information and data in the various systems of the company and associated contracted companies should be facilitated by an information infrastructure. This information infrastructure should enable the discovery, exchange and reuse of existing information and data instead of adding new systems with newly collected or copied data. If asset integrity management is set as the focal point, the information infrastructure becomes the nerve system of the pipeline asset integrity management organization. See Figure 18 for a graphical representation of this.

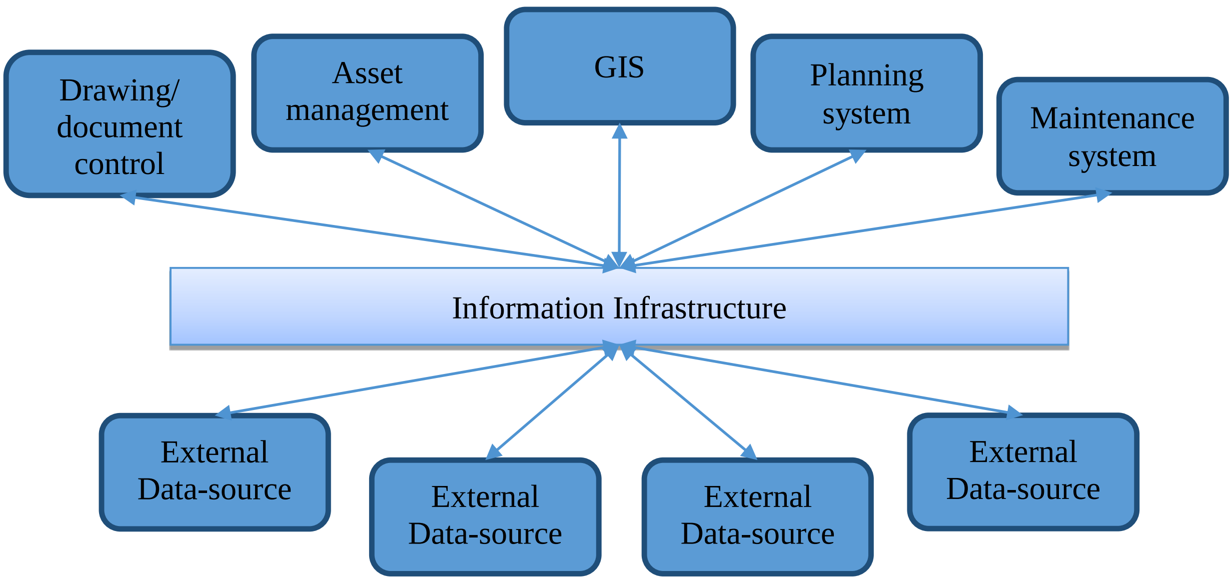


Figure 18: Information infrastructure for pipeline integrity management

The development of such an information infrastructure is a major task requiring ample resources from the organization. Expertise, time and money must be allocated, various inter- and intra-organizational parties should be involved and support from high-level management is key. This thesis research aims to contribute to the development of the information infrastructure by focusing on one specific part of it: SDI technical data issues for offshore pipeline integrity management.

4.2. Spatial Data Infrastructure (SDI)

A part of the infrastructure should be regarded as a spatial data infrastructure (SDI). Unmistakably, the pipeline network with all its associated objects has a spatial extent. Information and data about a pipeline network can relate to the whole pipeline network, to a single pipeline and to specific parts of a single pipeline. By relating the information and data to a specific location in geographic space having a relation with the Earth's surface, it becomes spatially enabled. By using a GIS (Geographic Information System)[5], spatial relations can then be defined and discovered and spatial analysis can be performed. Furthermore the temporal aspect to the information and data needs to be dealt with: on the one hand, certain properties of a pipeline can change throughout its lifetime, and on the other hand, conditions of the environment of a pipeline may change through time, as can be concluded from the description of the life-cycle stages of pipelines given in section 2.2 of this report. The changing conditions of the environment of a pipeline are subjected to further study in the use cases of this thesis as presented in section 3.4.

What, then, is necessary for pipeline integrity management, is a spatio-temporal approach of the information and data regarding pipelines in combination with an information infrastructure that takes into account data exchange and interoperability between different existing parties and systems and is adaptive and flexible enough to integrate information and data from new data sources. SDIs claim to do just this: they are "*an integration platform that facilitates interoperability and the interworking of functional entities within a heterogeneous environment.*" (Rajabifard, 2008, p. 16). By using standardized services, data can be exchanged and made interoperable by an SDI.

4.3. SDI and enterprise architecture

For the sharing and interoperability of spatial data and information a huge body of knowledge exist, focussed around the concept of Spatial Data Infrastructures (see (Williamson, Rajabifard, & Feeney, 2003), (Nebert, 2004) and many more). From the 1990's onwards the concept has been popularized (Grus, 2010, p. 13), and the last 10/15 years academic research into the subject has grown substantially (Rix, Fast, Masser, Salgé, & Vico, 2011, p. 24). In 2003 the Global Spatial Data Infrastructure Association was established (see http://www.gsdi.org/). In 2006 the first volume of IJSDIR (International Journal of Spatial Data Infrastructures Research) appeared to "*further the scientific endeavour underpinning the development, implementation and use of SDIs*", as is stated on the journals' website (http://ijsdir.jrc.ec.europa.eu/index.php/ijsdir). Most notably, in 2007 the INSPIRE directive entered into force, "*establishing an infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment*" (see http://inspire.ec.europa.eu/).

SDI's are multi-levelled, based on hierarchical spatial reasoning, integrating datasets from lower in the hierarchy into higher levels (see (Williamson, Rajabifard, & Feeney, 2003, p. 29)). This is also expressed as "*framework data development*" (Nebert, 2004). Figure 19 shows the hierarchical nature of SDI's.

[5] A GIS is a computerized system that helps in maintaining and displaying data about objects in geographic space.

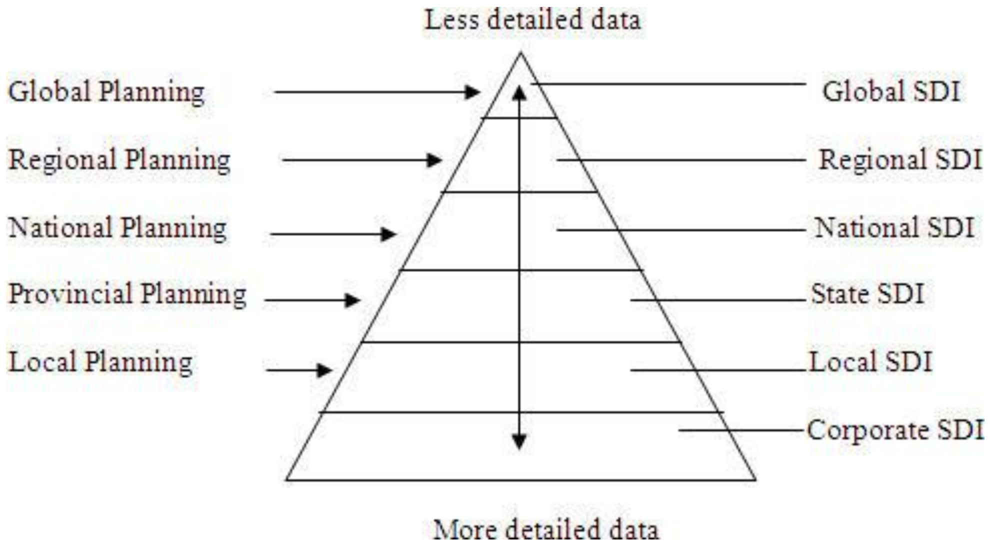


Figure 19: Hierarchical nature of SDI; from (Williamson, Rajabifard & Feeney, 2003, p. 30)

This means that a part of the data that is used in the corporate SDI, should be made available for the higher level Local SDI and so on, when applicable. Step by step, the SDI's interlock, until data can be exchanged on a global level. To do this, compliance with standards is paramount. As already shown in the introduction of this research, objective is to comply with these standards.

For this research about pipeline integrity management, the lowest level of SDI's is applicable: corporate SDI. However, it is to be noted that the majority of literature and research about SDIs is devoted to public SDIs. Corporate SDIs receive much less attention. To illustrate this, a simple search (performed in July 2014) in the journal content of IJSDIR on 'corporate' results in 0 hits. In comparison: 'public' results in 35 hits, 'local' 18, 'state' 17, 'national' 43, 'regional' 24, and 'global' 14. If 'corporate' is replaced by 'enterprise' (in many senses a synonym for 'corporate', the result is 1 hit. See Figure 20 for a graphical view of this result.

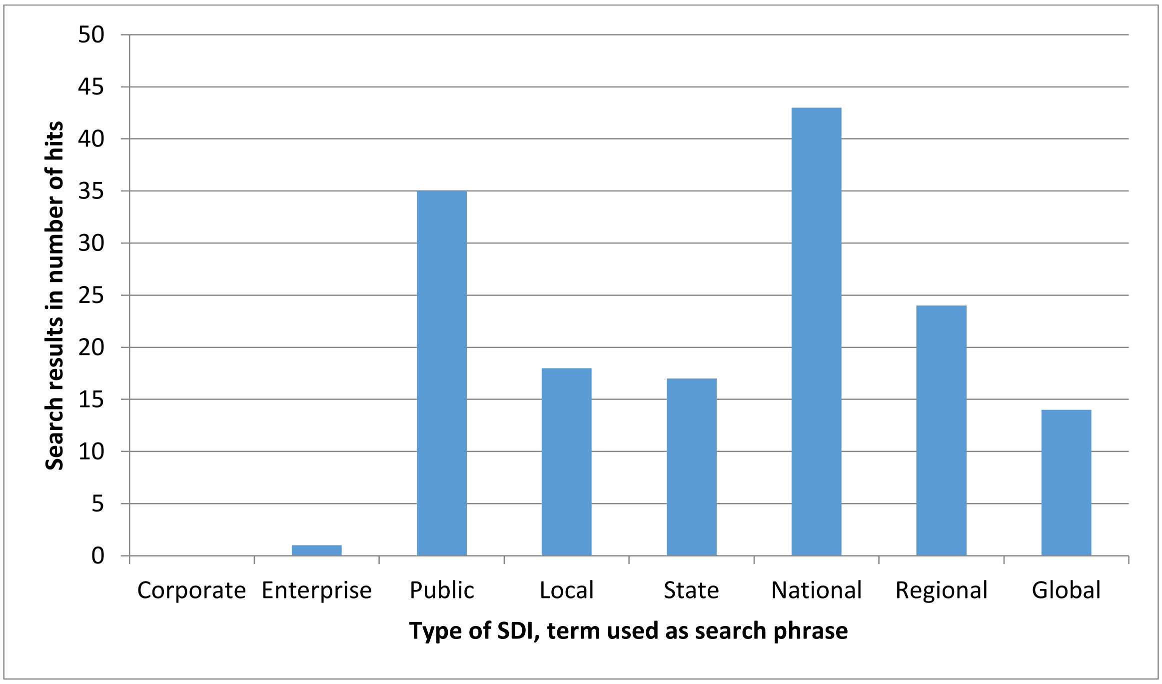


Figure 20: search results in IJSDIR journal content

A reason for this could be that with many different specialized applications that require highly detailed data, requirements of a corporate SDI are very specific and depend fully on the corporate organization at hand; as it turns out, too specific for academic research and literature in the field of SDI.

Another reason could be corporate competitiveness. Corporate SDI's might be developed in-house, with the intention to stay only in-house. A company can vest heavily in the development of technology. A return of investment can then only exists when other companies cannot just copy what has been developed.

Other fields of research, however, have vested a lot in interoperability at the corporate level, most notably the field of Enterprise Architecture. The next session gives a brief overview of the interoperability concepts for the corporate level.

4.4. Interoperability

Interoperability is a very wide concept. Different aspects on which interoperability occurs (or fails to occur) are identified: data, software (applications, systems), rules, processes, services etc (see (Jardim-Goncalves, Grilo, & Agostinho, 2012, p. 352). According to (Goodchild, Egenhofer, & Fegeas, 1997, p. 5), issues of interoperability for GIS can be assigned to three layers: technical, semantic and institutional. (Manso, Bernabe, & Wachowicz, 2009, p. 48) mention several levels of the nature of interoperability: Integrated, Unified, Federated. They proceed to propose an integrated interoperability model for SDIs, that combines multiple aspects of interoperability into one single model.

For this thesis research interoperability between different systems and the involved data is at stake. Interoperability of systems is defined by (Chen, Doumeingts, & Vernadat, 2008) as: "*the ability for two systems to understand one another and to use functionality of another.*" (Chen, Doumeingts, & Vernadat, 2008, p. 648). What is lacking in this definition, however, is a reference to the involved information or data. In a definition found in (Moen, 2012), information is identified. According to (Moen, 2012) interoperability can be defined as "*the ability of two or more systems or components to exchange information and use the exchanged information without special effort on either system.*" (Moen, 2012, p. 636)

The last part of this definition 'without special effort on either system' is of particular interest. The existing systems should not be altered, but where the effort should be put into, is not part of the definition: if not into the systems themselves, then somewhere in the context of the systems. For this research, this context is the organization of the company. This context is made up of different things: people, departments, policies, standards, computer systems, databases, networks etc. When the combination of all these things is understood as an enterprise, Enterprise Architecture can be used as an overall framework and it might become clear where the effort should be put into.

Enterprise Architecture (EA) is a tool to help stakeholders to manage system engineering and changes by looking at all factors involved: "*It defines the components that make up the overall system and provides a blue print from which the system can be developed.*" (Chen, Doumeingts, & Vernadat, 2008, p. 648). A central aspect in EA is the degree of coupling of the identified systems. Tightly coupled indicates a full integration of the systems, whereas loosely coupled means that the systems can inter-operate, but still have their own logic of operation. In the situation of the company where various systems already exist, full integration is deemed virtually impossible. The systems were not developed with a common meta-level structure providing semantic equivalence. Major changes would be necessary for the systems to be integrated. The inter-operating of the different systems throughout the whole organization, however, should be feasible.

How interoperability at enterprise level can be arranged, is studied in the field of Enterprise Interoperability. Current efforts (European commission programs ENSEMBLE, 2011, EISB) are underway to create an Enterprise Interoperability Science Foundation within the context of the IBoK (Interoperability Body of Knowledge). Three levels of specificity of work are identified for the creation of this foundation:
"*The study of Interoperability depends on theoretical work undertaken at three levels of specificity that are often confused with one another. These essential foundations include (1) frameworks, (2) theories, and (3) models.*" (Jardim-Goncalves, Grilo, & Agostinho, 2012, p. 353). Throughout these three levels, one concept seems to resonate: Semantic interoperability. The main issue that is related to this concept is: are we talking about the same things?

4.5. Spatial data and Semantic interoperability

A key aspect is to determine the relation between corporate SDI with the specific enterprise architecture. It has come to light that the role of SDIs in enterprise interoperability needs to be defined, particularly the spatial nature of information and data: is it just one of the many aspects of object information, or should it be the structuring principle of the data? If the latter, what is the reason for the special status of spatial characteristics? Is there a fundamental reason to support this? At the moment, there is no evidence in the literature of integration of SDI principles in enterprise architecture and enterprise interoperability. For this research, SDI is seen as a part of the enterprise architecture.

Space can be seen as an organizing principle; things in the real world – objects – have spatial relationships with other objects or fields (natural phenomena that change gradually over an area - a continuous surface - such as elevation, temperature, humidity, saliency etc.): they are next to, underneath, above, and/or at a certain bearing and distance (proximity). They can also have topological (connectivity and continuity) relations: they are connected, contained, containing and/or are neighbors (share boundaries). Because of these spatial characteristics, information about objects can easily be made visual in a map by using the spatial characteristics of the object. To compute the spatial relationship of objects (intersection, proximity, connection), the characteristics of the objects need to be stored in database that is structured in special way: a spatial database (or geodatabase) with topology.

Storing the spatial characteristics of an object by means of a geometric description (coordinates in a specified coordinate reference system), in a database that is connected to an application 'spatially enables' the object. A vast amount of information and data is not 'spatially enabled', but it can be located because it is about a specific object that is spatially enabled. This information and data is indirectly spatial. How much and which part of the information and data that is not spatially enabled should be made spatially enabled?

One of the common characteristics of SDI's and enterprise architectures is semantic interoperability – having unambiguous, shared meaning. For the oil and gas industry a lot of work has already been put into semantic interoperability with regard to objects and assets belonging to process plants. ISO standard 15926 is the result of this work. A logical step would be to use these developments for pipeline objects as well.

The next chapter continues with the concept of semantic interoperability, when the attention shifts to finding methods to model pipelines, seabed and permits according to (inter)national and domain specific standards. At the end of that chapter, the conceptual model for the SDI for this research is presented.

5. Modelling the pipeline object, seabed data and permits

The goal of this chapter is to come up with a method to integrate different data models on a conceptual level and to implement them in a technical model in the context of a SDI for offshore pipeline integrity management. The technical model should resemble the databases that are already implemented at the company, most notably the PODS database.

This chapter starts with describing which standards can be related to the involved data sources for modelling. First, characteristics of the data sources that should be considered during modelling are briefly mentioned (section 5.1). Then the general geometry standards are considered. Next, application domains of the standards are addressed and finally, also the industry standards (section 5.2). Then, looking back to section 4.5, methods to compare the different models with each other are discussed in section 5.3. Finally, at the end of this chapter a data model will be presented that should make the integrated use of data sources possible (section 5.4).

5.1. Modelling characteristics of data sources

While doing research in schematization and database modeling for pipeline, seabed and permit data, specific attention is given to:

1. 3d representation of pipeline object
2. Linear referencing
3. Temporal characteristics
4. Thematic semantic information
5. Data quality issues (lineage, topology, constraints)

Pipelines are a specific type of object. They can be very long and characteristics can change over the length of the pipeline. Yet, it is still the same object. Information about the pipeline can relate to the whole pipeline, but also to a specific part of the pipeline. This can be just one point, but also multiple points along the length of the pipeline. Furthermore, throughout its lifetime, a pipeline exists in different ways: a concept route, an engineering line, a construction line, a production line etc. Also, values for a specific variable at a specific location on the pipeline might change from time to time.

In making a data model for integrity management of pipelines, these characteristics (measurement along the length of the pipeline and temporal variation) are an essential component. How these components can be included in the model is investigated by analyzing different data models that already exist that deal with pipeline objects.

The seabed as a phenomenon is a continuous field. Under the sea, it's everywhere and bathymetric data records the elevation of the seabed. However, the way to measure the seabed and the methods of storing and accessing the data are very challenging. The amount of data can get huge, while only a small part of the data will actually be used. Moreover, data quality can be an issue and metadata about the acquisition methods, used vessels, tidal reduction method, survey program and many other issues poses specific requirements.

Permits are yet different kind of object. The permit itself is hardly spatial (the piece of paper it is printed on), but it can refer to an area where it is applicable by means of regulations, conditions and/or restrictions. The ISO standard for the Land Administration Domain Model (ISO 19152) could be a possible model for this, see (Zulkifli, et al., 2014).

5.2. Standards

As was discussed in section 4.5, interoperability can be achieved by developing a uniform vocabulary in which all objects, units, dimensions etc. are defined. This definition of objects, attributes and operations, is called an ontology[1]. The ontology is the basis for the exchange of data and is the core in behind the standards of SDIs. Ontologies can help to achieve semantic interoperability. By defining standards, the ontologies can get agreed and formalized. If the standards get international recognition and more and more people use the standards, semantic interoperability is getting closer.

The first step in modelling is schematization: "*the process of intentionally simplifying a representation beyond technical needs to achieve cognitive adequacy*" (Peters & Richter, 2008). Through abstraction, idealization and selection the schema must be achieved. In the schema the involved objects and their relationships are defined. Most of this work has already been done by (inter)national standardization. The result of this work is discussed in this section.

First, the way how a pipeline, the seabed and permits can be modelled based on its geometric properties and its thematic semantic information is investigated by studying the NEN 3610:2011, ISO TC/211 19100 series, the Dutch IMKL and INSPIRE generic model and relevant application schemas. Next selected industry standards PODS and SSDM will be related to the standards.

As discussed in section 2.3, various industry standards for pipeline integrity management exist. Hardly any of these standards pay attention to data, let alone spatial data. The standards focus mostly on pipeline design requirements and inspection and analysis methodologies. Reference to (inter)national data standards is required for these industry standards if they are to play a role in the interoperability between existing systems that deal with pipeline integrity management is to be achieved.

NEN 3610/ISO 19100 series

For the Netherlands, the basic schema for (the exchange of) geo-information NEN 3610:2011 is part of a system of information models. It deals with terms, definitions, relations and general rules for the interchange of information of spatial objects related to the earth. The basic schema is operationalized by application in a sectoral model. One such sectoral model in the Netherlands that deals with pipelines is the IMKL (Informatie Model Kabels en Leidingen), in Europe the Inspire directive, annex III and internationally, currently in development by the OGC, the PipelineML standard.

NEN 3610:2011 is based on international standards (ISO 19100 standards, OGC) on geo-information (see Figure 21) and can be linked with INSPIRE, the European standard for data specifications. Discussing NEN 3610:2011, implies ISO 19100 series.

[1] This term should not be confused with the field of ontology in philosophy (the logos of being), most notably Heidegger's Sein und Zeit. Where Heidegger studies the being of things, ontology in the sense of semantic interoperability is about the characteristics of things, more specifically about how these characteristics can be expressed consistently. When expressed consistently, different applications and systems can use the same information.

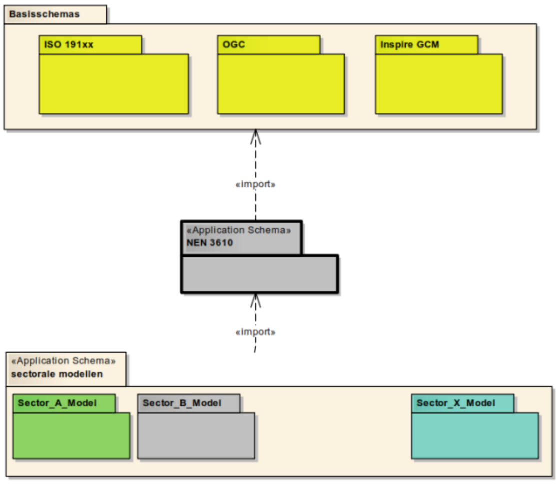


Figure 21: NEN 3610:2011 - international standards; from (NEN 3610:2011, p. 15)

The components (models) of NEN 3610:2011 are discussed briefly where they are relevant for modelling for this thesis. Components that are included are: Basic types and stereotypes, Reference model, Semantic model, Network model, Measurement model, Aggregation model and Portrayal model.

Basic types and stereotypes

This is the core of the model. Basic types are elements that have a central role in the model. Stereotypes are created for identification and the documentation of formal and material history of objects. Furthermore data types and void values are described. The main basic types are the featureType GeoObject and the featureType IM_X_object that has a couple attributes with specific stereotypes for the implementation of the temporal model.

Reference model

The reference model of NEN 3610:2011 describes how different classes of objects are related to each other and how the geo-information relates to other information. Geo-objects are subclasses of Objects (see Figure 22). The specific characteristic of Geo-objects is that they have a reference to a location on earth. The location can be either directly (coordinates) or indirectly (address) expressed. According to this characteristic pipelines and permits for risk based integrity management are geo-objects. In fact, a pipeline network is a network object.

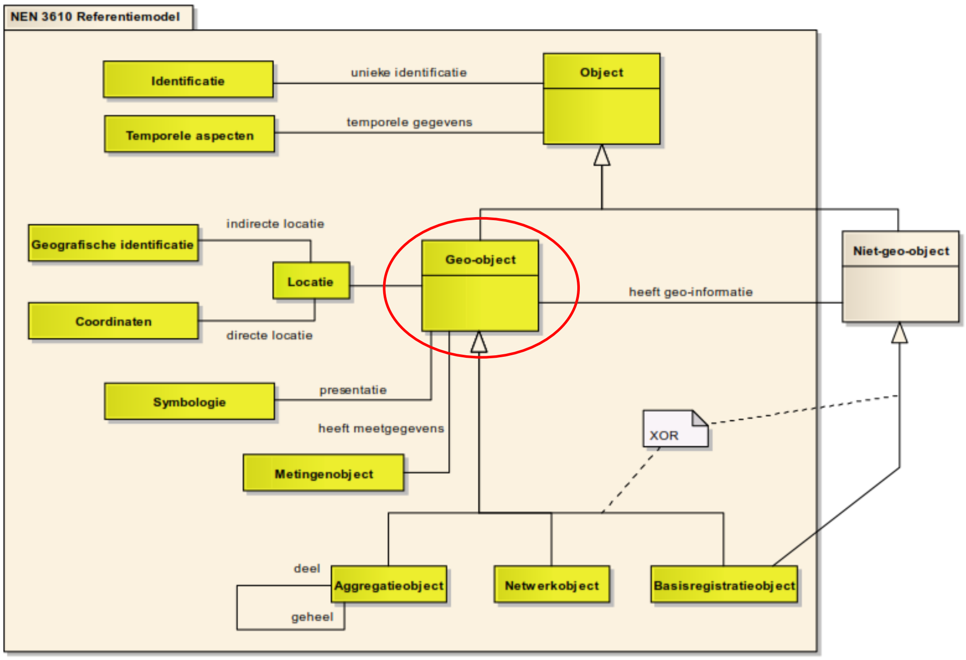


Figure 22: NEN 3610:2011 Reference Model, taken from NEN 3610:2011

Semantic model

Instances can only be made from subclasses of Geo-objects, not of the superclass Geo-objects itself. Conform ISO 19109:2005, these subclasses have the stereotype <<feature type>>. In the semantic model of NEN 3610:2011, feature type 'Leiding' is one of the twelve main subclasses of the superclass Geo-object (see Figure 23), and can be used for pipelines. For permits for risk based integrity management, feature type 'GeografischGebied' and 'RegistratiefGebied', can be used.

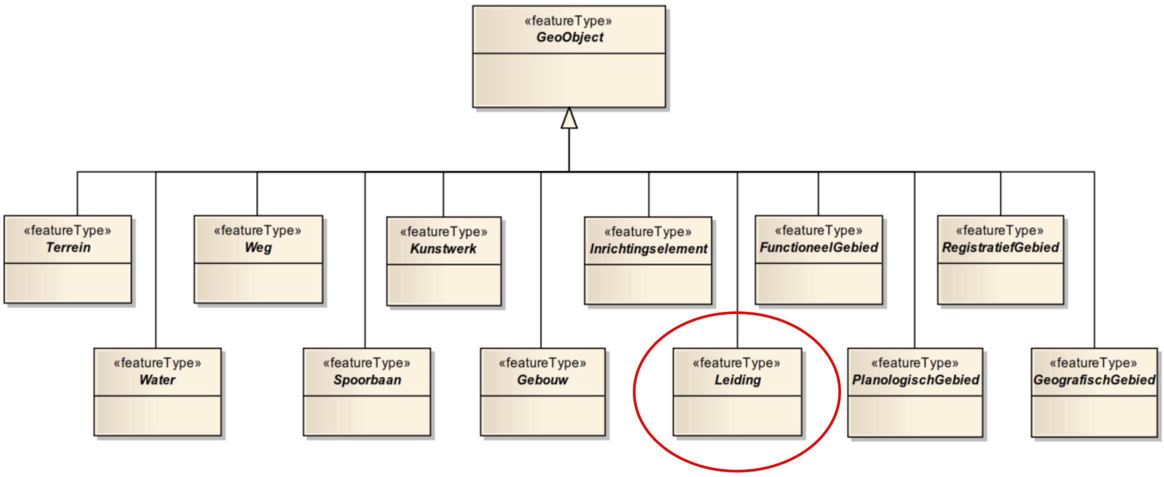


Figure 23: Pipeline as main class in NEN 3610:2011. Taken from NEN 3610:2011, p. 35.

Network model

For a pipeline system, geometric and/or topologic relations are elementary. Without connectivity, the system wouldn't function. According to NEN 3610:2011 this connectivity should be modelled as a network between geo-objects (geographic features) that are described in the generic network model of INSPIRE. This generic model consists of abstract classes. To use these abstract classes, a sectoral model is created that translates the abstract classes into specific subtypes. Objects in sectoral models are then related to the generic model.

Geo-objects in the domain models are linked to nodes, links, areas, connections, grade separated crossings and aggregated links of the INSPIRE generic network model by a simple relationship. For elements related to a specific part of a link, linear referencing is included in the networkmodel.

Measurement model

In NEN 3610:2011 measurement data is also considered as a geo-object when the location of the measurement is of relevance. A complex relationship between the geo-object and the measurement then exists. OGC/ISO standard ISO 19156 (Observations & Measurements model) describes how these measurement data can be exchanged consistently. For the Netherlands IM-Metingen describes this. For pipeline integrity database modelling, measurements of the height of the seabed (bathymetry), soil samples, Cone Penetration Tests are of relevance. These measurements should be related to the pipeline route.

Aggregation object model

If geo-objects are composed of other geo-objects, aggregated objects can be made. For pipelines, the different components could be Upper riser, Lower riser, spool pieces, sea-pipe, flanges and valves, however, these components are not described as geo-objects in the standard. Some kind of aggregation is considered, so that all the components are considered by the model to be a part of the same aggregated pipeline object, but due to time and resource restrictions this part is put aside for possible further developments of the SDI.

Portrayal model

For the exchange of a portrayal model and the relation with an information model, NEN 3610:2011 refers to INSPIRE and OGC Symbology and the Styled Layer Descriptor (SLD) standard, in combination with the use of OGC Web Services.

Other

Other relevant aspects that are covered by NEN 3610:2011 are conventions for modelling, coordinate reference systems, metadata and a description how NEN 3610:2011 can be implemented in sectoral models.

IMKL - Onshore

The WION (Wet Informatie-uitwisseling Ondergrondse Netwerken) prescribes the rules, systems and actions required to prevent excavation damages to pipelines and cables onshore. On the one hand, managers of cable and pipeline networks are obligated to share data about (the location of) their networks and on the other hand, companies involved in excavating activities are obligated to check for each location of an excavation activity whether pipelines and/or cables are reported. To facilitate this, the Dutch Kadaster has created the information model IMKL (Informatie Model Kabels en Leidingen) in consultation with network managers. In principle it is an implementation of the geo-object classes in the basic schema of NEN 3610:2005, as far as they are relevant for the domain of cables and pipelines and they are involved in the information needed for the exchange of data to prevent damages as a result of excavation activities[2]. However, IMKL doesn't use the attributes of NEN 3610:2005, so there is no functional relation between NEN 3610:2005 and IMKL.

[2] See Staatscourant 2010 nr. 4615, 22 maart 2010, p. 7.

Since this research is mainly about subsea pipelines, none of the original intention of the IMKL is of relevance. However, the model itself can be of interest. Noted should be that the reference is to the old and updated version of NEN 3610, and that reference to INSPIRE is lacking. The Belgian IMKL however, is integrated with INSPIRE Utility And Government Services. An update of the Dutch IMKL along these lines might be expected, but no mention of this can be found on the internet.

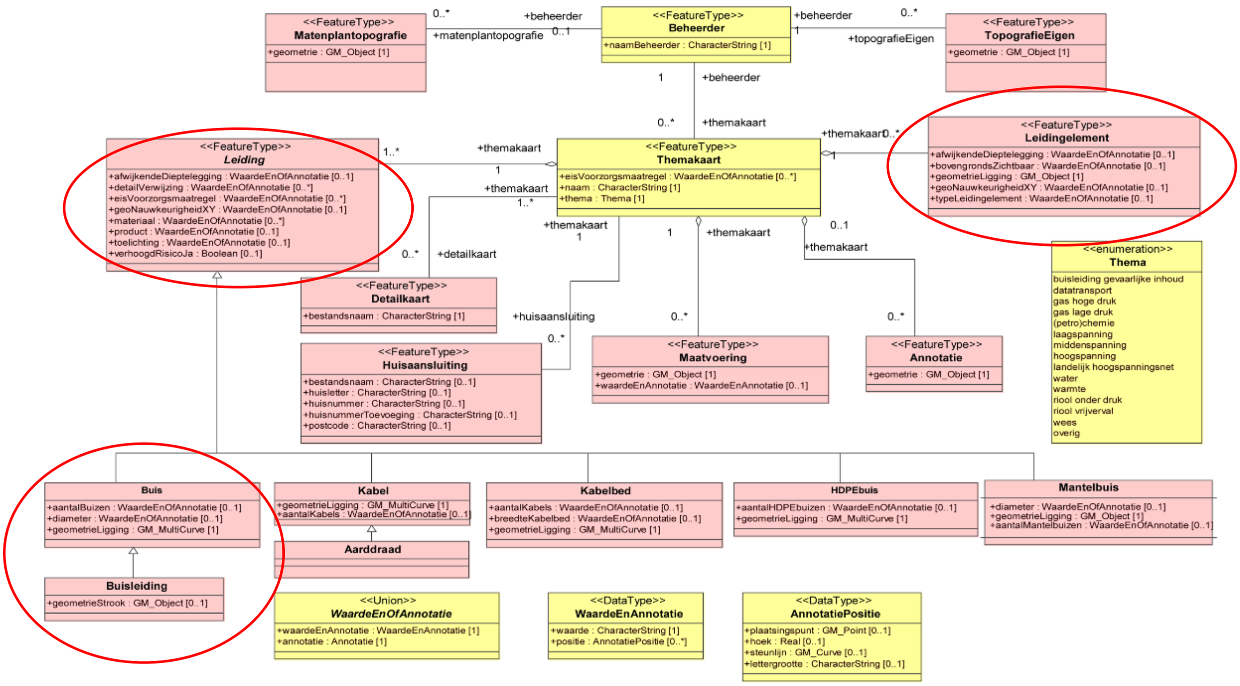


Figure 24: IMKL UML class diagram, taken from Staatscourant 2010, nr. 4615, 22 maart 2010

Relevant object classes in this model (see Figure 24) are the feature type 'Leiding', its specialization 'Buis', which is further specialized into 'Buisleiding' (Pipeline), and the feature type 'LeidingElement' (pipelinecomponent). The expression of the geometry and is defined in relation to ***external objects***. In the model references to the geometric properties can be found. For the class 'Leidingelement' (pipelinecomponent) reference is made to the geometrytype GM_Object, for the class 'Buis' (Pipe) the geometry is expressed with a the textual reference to a heartline, which according to the diagram should be a GM_MultiCurve. The class 'Buisleiding' is expressed by the geometrytype GM_Object.

The IMKL will not be considered further, although it is interesting to note that this model refers to NEN 3650-1:2003 Eisen voor buisleidingsystemen – Deel 1: Algemeen.

INSPIRE

In 2007 a directive of the European Parliament adopted aims at establishing INSPIRE for environmental policies. To support this, implementing rules addressed a number of components related to spatial data and services. A development framework is used to keep the data specifications of the 34 different themes of INSPIRE coherent. Three annexes were adopted: I, II and III with their own data themes and different dates of entering into effect.

The INSPIRE Directive aims to establish an Infrastructure for Spatial Information in the European Community. In that context interoperability means '*the possibility to combine spatial data and services from different sources across the European Community in a* *consistent way without involving specific efforts of humans or machines.*' (see (INSPIRE, 2013, p. III). This touches the objectives of this research. The technical guideline specifically mentions that '*the data specification development framework and the thematic data specifications can be reused in other environments.*' (INSPIRE, 2013, p. V)).

Generic conceptual model

A Generic Conceptual Model defines the elements necessary for interoperability and data harmonization. Figure 25 shows the role of the generic conceptual model. The ISO 19100 standard is applicable to the generic model, which in turn is applicable to the application schemas. Like NEN 3610, INSPIRE refers to the ISO 19100 series for the definition of geometry (see (INSPIRE, 2013, p. 6)). For this research, also ISO 19100 series will be used as standard for describing geometry.

Three of the INSPIRE application schemas might be applicable to this research:

- Area Management/Restriction/Regulation Zones And Reporting Units (Permit information)
- Elevation (Seabed data)
- Utility And Government Services (Pipeline)

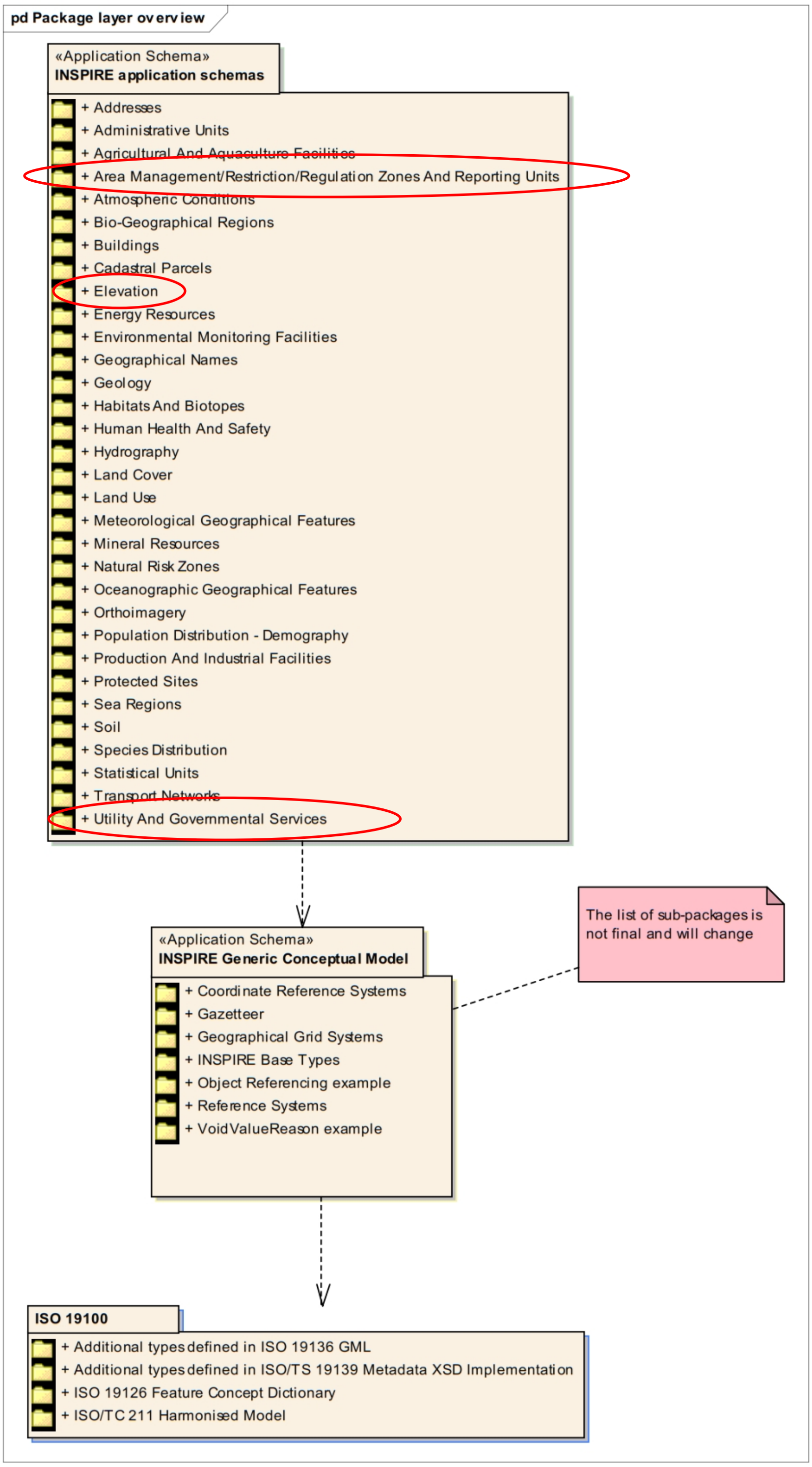


Figure 25: Role of generic conceptual model in INSPIRE

Application schema 'Area Management/Restriction/Regulation Zones And Reporting Units'

For Permit information this Annex III application schema might be consulted. In (INSPIRE, 2008, p. 98), important types and attributes of this theme are given:

- Management region
  - Sector
  - sub-sector

  - management activity type
  - responsible organization
  - year of verification

Application schema 'Elevation'

For seabed data, the Annex II application schema 'Elevation' might be consulted. In (INSPIRE, 2008, p. 48), important types and attributes of this theme are given:

- Core data:
  - DEM and/or DTM as regular grid, in different resolutions, for land and sea bottom.
  - TIN (Triangular Irregular Network)

- Additional data:
  - Contour line and depth contour:
    - Altitude
  - Breakline
    - category (crest, thalweg, other)
  - Spot height
    - Altitude
    - category (summit, mountain pass, …)
    - name
  - Sounding
    - altitude
  - High and low water line

Application schema 'Utility and Government Services'

For pipeline data the Annex III application schema 'Utility and governmental services' might be consulted. In (INSPIRE, 2008, p. 82), important types and attributes of this theme are given:

- Pipeline - oil, gas, heat
  - category of content
  - segment id
  - capacity, max
  - average volume
  - diameter
  - pressure regime
  - construction system
  - date of construction
  - responsible organization

The INSPIRE data specifications (like (INSPIRE, 2013) as cited before) provide more specific information about the application schemas. However, for this research implementation of the INSPIRE application schemas is not feasible due to time constraints. Recommended is that for further development, the data specifications of the various application schemas of INSPIRE are used.

OGC PipelineML Standards Working Group

A charter document was issued on 28-03-2014 by the OGC (Tisdale, Strahan, & De Lathouwer, 2014). In this document the start standards working group in June 2014 is announced. The document further states that PipelineML should support the work of the PODS association, and ISO 15926.

As objective is stated:

Effectively share and communicate of pipeline data should result in:

- provide better customer service
- reduce risks
- enhance public safety
- reduce environmental impacts
- reduce operational costs
- enhance the reuse and value of information assets related to the pipeline infrastructure

The working group is currently underway in defining a data and exchange model for pipeline data. Results have not been published for this thesis research.

ISO 15926

As discussed earlier, the ISO 15926 standard, arranges the semantic interoperability required for process plant objects and assets. ISO 15926: ISO 15926 falls under TC 184 (Automation Systems and Integration) SC 4 (Industrial Data). The technologies used in these standards should be applicable to pipeline integrity management as well.

Being part of an Engineering & Construction department of an Exploration & Development company, most of the work is about process plants (platforms). Pipelines are commonly perceived as assets that connect different process plants.

The lexical scope of all the assets, their properties, variables and measures involved in the process industry is defined by ISO 15926. Semantic precision is to be attained by its specification for a reference data library (RDL). Whether or not this should be a public extensible dictionary, is still at debate. Figure 26 shows the elements that the standard tries to bring together.

ISO 15926 has borrowed two technologies from the Semantic Web: OWL (Web Ontology Language) and RDF (Resource Description Framework). OWL is a language for creating ontologies. RDF is a way of storing information in declarations of truth using specific vocabularies, or ontologies, in a manner that makes the meaning machine readable.

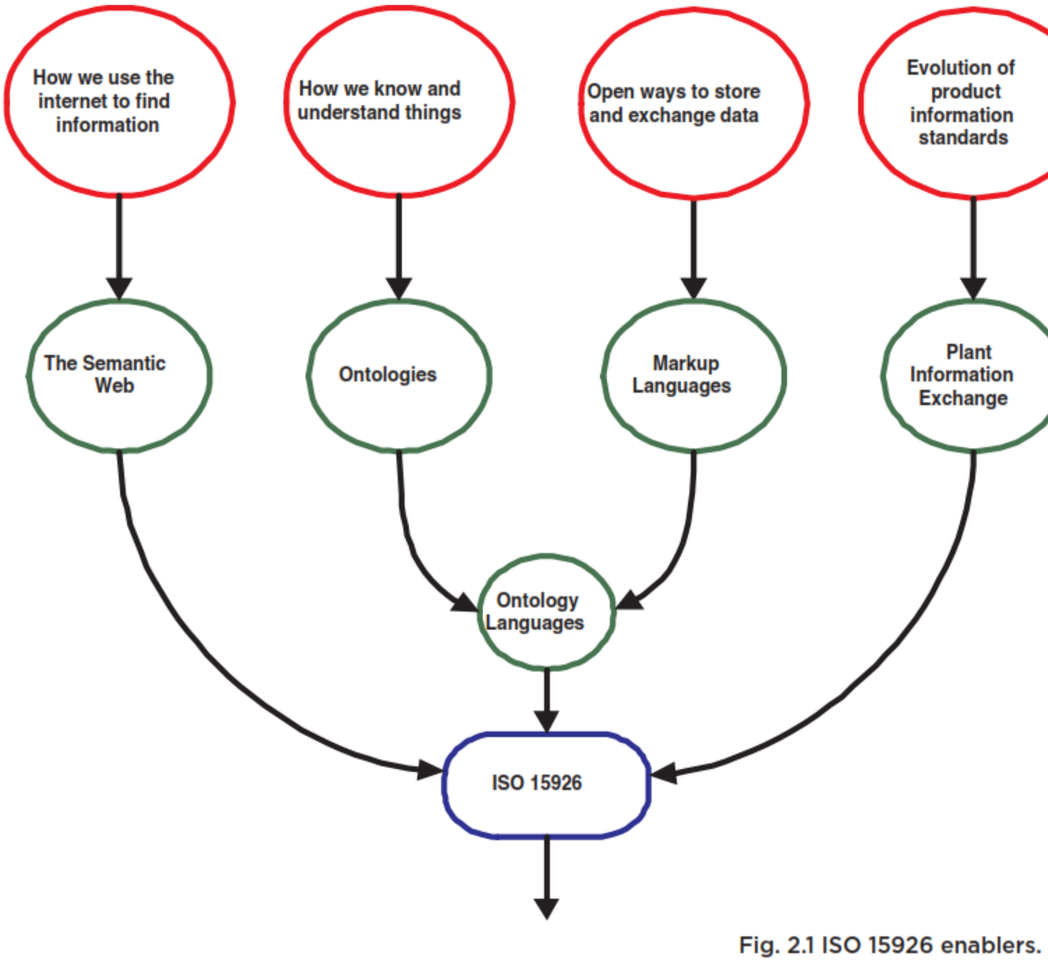


Figure 26: The convergence of four areas of study for ISO 15926, taken from (Fiatech, 2011)

ISO 15926 provides protocols (services) to exchange data. 15926 RDL assigns a unique identifier to each definition so that the identifier can be used like a serial number for the definition. An Uniform Resource Identifier (URI) points to this definition, so that different machines can 'understand' the content of the data.

A similar way, an SDI might work with pipeline data. However, to go study these possibilities are far beyond the scope of this research. Recommended however is, that a companywide strategy considers including Enterprise Architecture, SDI development and ISO 15926 implementation in a joint project.

PODS (Pipeline Open Data Standard)

This standard defines a database schema for data is related to pipeline (integrity) management. As this standard is already implemented in company's systems, it is the starting point for developing the model for the SDI. Actual changes and/or additions to the implemented standard are not welcome from the perspective of the company.

Through ROAIMS for pipelines (see section 3.3) all data currently related to pipeline integrity management in the company is modeled by the PODS data standard. For this thesis research, this will remain the same. This data standard plays a central role in the company's efforts to organize the existing pipeline data. Changing to another model is deemed not favorable for the development of the integrity management system. It must be noted, though, that the PODS data model is extremely complex and not recognized by international standardization organizations like ISO.

The PODS open data standard is developed by the technical committee of the not-for-profit PODS Association to '*develop and support open data storage and interchange standards to meet the specific data management needs of pipeline companies.*' (PODS website; http://www.pods.org/9/The%20Association/ consulted on February 12, 2015). Historically, PODS originated at the Gas Research Institute, an US government body, as ISAT (Integrated Spatial Analysis Techniques) in 1994. Just as PODS is now, ISAT was a relational data structure for pipeline hierarchy, centerline, facilities and related events. Throughout the years, the standard became more complex in order to manage more and more pipeline related data. In 1998 the expansion of ISAT resulted in PODS.

The PODS association is one of the partners involved in the Energy & Utility domains of OGC (see OGC website; http://www.opengeospatial.org/domain/EnergyUtilities consulted on February 12, 2015).

PODS 6.0 is the latest release, however ROAIMS for pipelines is based on PODS 5.1. Since this release is implemented in the company's systems, PODS 5.1 is the release used in this thesis. No conceptual model is available for PODS, only a template for the physical database model. See Figure 27 for the entire ERD (entity relationship diagram), an overview for the tables involved in the PODS database. A total of 678 tables are involved.

For this thesis, only a small part of the data in the tables of the database is required: those related to the stationed centerline and the geometry. Relevant parts of this physical database model are reversed engineered into a conceptual model for the company pipeline integrity management system.

Figure 27: PODS 5.1 ERD; taken from (PODS - Pipeline Open Data Standard, 2014)

PODS and centerline definition

PODS defines a pipeline as a centerline, a pipeline hierarchy that uniquely describes each individual pipeline. The main objects of the hierarchy are: Line, Route, Series and Station points. A line is composed of one or more routes, a route of one or more series and a series has many station points. A station point is a unique point on the pipeline where something of interest happens. This can be a change in pipe characteristics, a coating change, a crossing etc. A station point has a measure value by which the linear position on the pipeline is expressed.

All event data (features, characteristics, operation, surrounding) is linearly related to the pipeline through the table Event_Range. For linear features, the start and end station point are defined. For point features, just a station point is defined.

A Series is a continuous range of station points. A Route is a composition of one or more Series. A Line is a composition of one or more Routes. See Figure 28 for the tables dealing with the stationed centerline in PODS.

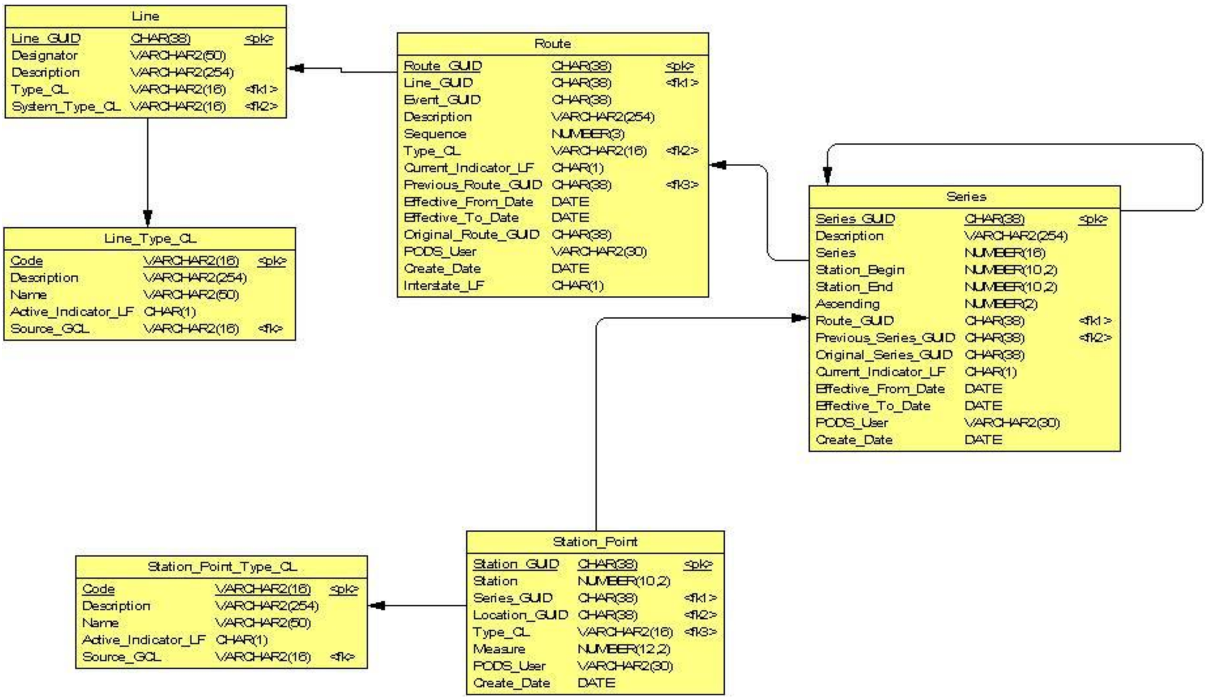


Figure 28: Diagram Stationing tables in PODS 5.1

Example query:
To get an overview of events on a stationed centerline, an SQL query can be made. [taken from: http://eaglemap.com/blog/bid/74520/How-to-query-events-on-a-particular-route-in-PODS, consulted on February 13, 2015]:

First join the line, route and series tables:

```
select * from line l, route r, series s1, series s2 where
r.route_guid = ???
and r.line_guid = l.line_guid
and s1.route_guid = r.route_guid
and s2.route_guid = r.route_guid
and s1.current_indicator_lf = 'Y'
and s2.current_indicator_lf = 'Y'
```

Next join the station point table:

```
select * from line l, route r, series s1, series s2, station_point sp1, station_point sp2 where
r.route_guid = ???
and r.line_guid = l.line_guid
and s1.route_guid = r.route_guid
and s2.route_guid = r.route_guid
and s1.current_indicator_lf = 'Y'
and s2.current_indicator_lf = 'Y'
and sp1.series_guid = s1.series_guid
and sp2.series_guid = s1.series_guid
```

If specific data from one of the related tables in PODS is required, the event range and feature tables can be joined. See Figure 29 for these tables.

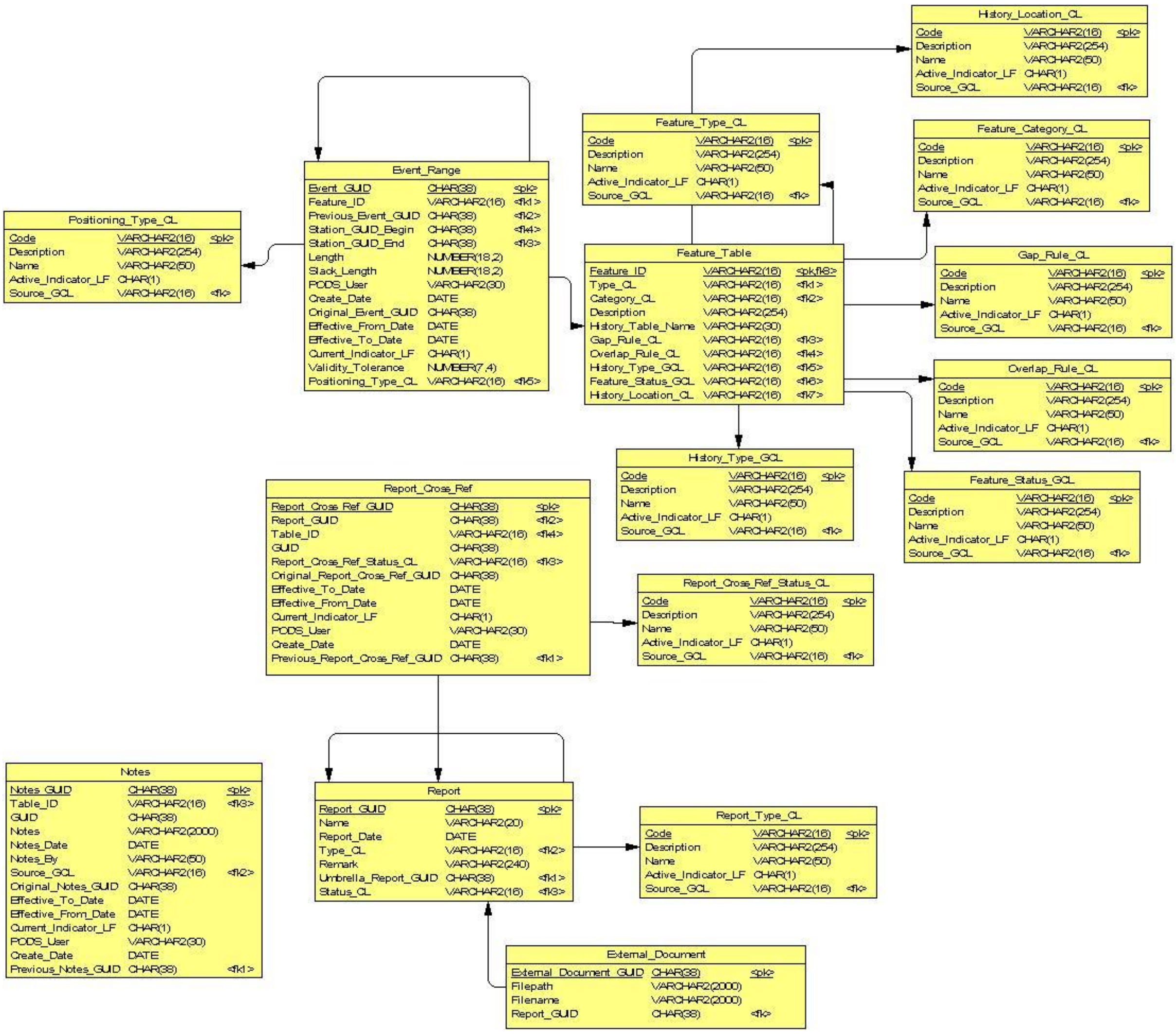


Figure 29: Diagram Event_Range tables in PODS 5.1

The SQL statement would read like this:

select * **from** line l, route r, series s1, series s2, station_point sp1, station_point sp2, event_range er, feature_table ft
where
r.route_guid = ???
and r.line_guid = l.line_guid
and s1.route_guid = r.route_guid
and s2.route_guid = r.route_guid
and s1.current_indicator_lf = 'Y'
and s2.current_indicator_lf = 'Y'
and sp1.series_guid = s1.series_guid
and sp2.series_guid = s2.series_guid
and er.station_guid_begin = sp1.station_guid
and er.station_guid_end = sp2.station_guid
and er.current_indicator_lf = 'Y'
and ft.feature_guid = er.feature_guid

PODS and geometry

The original physical PODS database is developed as a GIS platform independent non-spatial relational database However, from version 5.1, a special deliverable of the PODS association is PODS ESRI spatial. This is designed as an implementation of the PODS data model in an ESRI Geodatabase. Company has decided to implement original relational PODS in the company standard MsSQL 2012 server RDBMS (non-spatial) with the choice for Rosen

ROAIMS for Pipelines. A selection of pipeline data is gathered and stored in the PODS database implemented on the MsSQL server.

The PODS data standard is implemented in a non-spatial databases, although it contains spatial data. For the spatial features, the standard is not compliant with international (ISO) standards for geometry (ISO 19100 series, TC/211). For this thesis research an extension of the PODS Data Model is required to make the company data compliant with international (ISO) standards for geometry (ISO 19100 series, TC/211), the Dutch IMKL and the European INSPIRE directive.

Geometry in PODS is stored in the table ‘Coordinate’. See Figure 30 for the submodel diagram of the Coordinate tables. Geometry for all features related to the pipeline centerlines is stored in this table by means of the stored station point on the pipeline centerline. This means that although the features might have their own spatial characteristics, only the linear edge they share with the pipeline centerline gets stored in the PODS database.

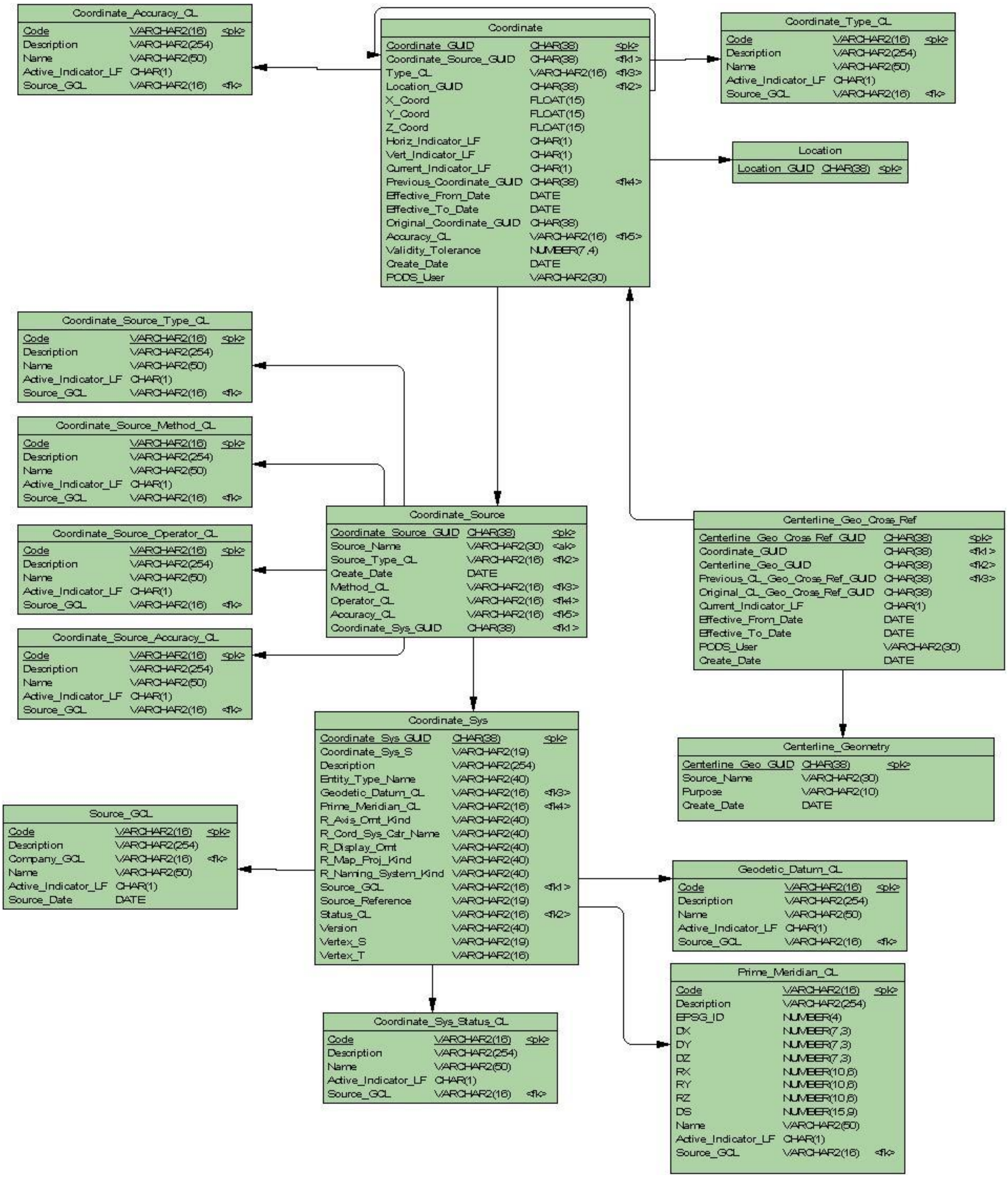


Figure 30: Diagram Coordinate tables in PODS 5.1

To get the geometry of the pipeline centerline, an SQL query can be made. [taken from: http://eaglemap.com/blog/bid/75426/Viewing-Coordinate-Data-from-PODS-in-Google-Earth , consulted on February 13, 2015]:

```
select r.route_guid,
       r.description,
       s.series,
       sp.station,
       sp.measure,
       c.x_coord,
       c.y_coord,
       c.z_coord
 from route r, series s, station_point sp, location l, coordinate c
```

```
where r.description = TP-002
  and s.route_guid = r.route_guid
  and s.current_indicator_lf = 'Y'
  and sp.series_guid = s.series_guid
  and l.location_guid = sp.location_guid
  and c.location_guid = l.location_guid
  and c.current_indicator_lf = 'Y'
order by sp.measure
```

The result of the query is shown in Figure 31.

Microsoft Query - [Query from ROAIMS]

ROUTE_GUID	DESCRIPTION	SERIES_GUID	STATION	MEASURE	X_COORD	Y_COORD	Z_COORD
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149094.043	149094.043	615576.3250000000	5860634.6430000002	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149097.070	149097.070	615579.3500000000	5860634.5369999995	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149098.051	149098.051	615580.3310000000	5860634.5250000004	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149104.376	149104.376	615586.6510000000	5860634.2699999996	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149105.339	149105.339	615587.6130000000	5860634.2369999997	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149111.327	149111.327	615593.6000000000	5860634.1040000003	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149110.466	149110.466	615592.7389999999	5860634.1100000003	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149113.701	149113.701	615595.9730000000	5860634.0300000003	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149114.522	149114.522	615596.7940000000	5860634.0219999999	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149114.352	149114.352	615596.6240000000	5860634.0180000002	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149116.847	149116.847	615599.1170000000	5860633.9270000001	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149115.986	149115.986	615598.2560000001	5860633.9630000005	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149130.224	149130.224	615612.4810000000	5860633.3490000004	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149132.550	149132.550	615614.8050000001	5860633.2429999998	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149130.244	149130.244	615612.5010000000	5860633.3490000004	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149132.570	149132.570	615614.8250000000	5860633.2439999999	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149132.680	149132.680	615614.9350000001	5860633.2470000004	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149132.700	149132.700	615614.9550000000	5860633.2470000004	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149150.086	149150.086	615632.3250000000	5860632.5199999996	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149134.877	149134.877	615617.1290000000	5860633.1480000000	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149156.101	149156.101	615638.3350000000	5860632.2670000000	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149191.853	149191.853	615674.0560000000	5860630.7709999997	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149192.437	149192.437	615674.6380000000	5860630.7270000000	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149193.340	149193.340	615675.5400000000	5860630.6820000000	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149193.320	149193.320	615675.5200000000	5860630.6809999999	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	149202.964	149202.964	615685.1560000000	5860630.2889999999	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148388.000	148388.000	614875.0000000000	5860715.0000000000	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148425.022	148425.022	614911.7260000000	5860710.3289999999	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148524.981	148524.981	615011.0850000000	5860699.3880000003	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148544.164	148544.164	615030.1530000000	5860697.2980000004	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148559.166	148559.166	615045.0670000000	5860695.6720000003	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148581.988	148581.988	615067.7490000000	5860693.1519999998	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148573.504	148573.504	615059.3180000000	5860694.0980000002	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148595.253	148595.253	615080.9360000000	5860691.7079999996	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148603.704	148603.704	615089.3370000001	5860690.7910000002	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148618.131	148618.131	615103.6780000000	5860689.2199999997	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148629.564	148629.564	615115.0400000000	5860687.9450000003	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148636.710	148636.710	615122.1450000000	5860687.1820000000	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148638.034	148638.034	615123.4600000000	5860687.0290000001	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148640.055	148640.055	615125.4669999999	5860686.7949999999	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148643.296	148643.296	615128.6890000000	5860686.4440000001	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148652.240	148652.240	615137.5810000000	5860685.4809999997	.000
EFC6422B-4367-4703-B	TP-002	510A7D04-0012-4EC7-E	148649.029	148649.029	615134.3890000000	5860685.8320000004	.000

Record: 1

Figure 31: Query results route TP-002

Using the fields of this table, results in the geometry of the pipeline centerline. Various methods can be used to use the geometry in a preferred application. Company standard is ESRI ArcGIS. All pipeline centerlines are created with this application. For convenience the data used as input data for the geometry of the centerlines in the PODS database is used as working dataset for this research. All attributes in the PODS database can be associated with the pipeline centerlines.

SSDM

The Seabed Survey Data Model (SSDM) has been developed by the OGP geomatics commission in collaboration with Shell and Woodside and survey companies FUGRO and DOF Subsea. The datamodel is based on the ESRI Geodatabase format and provides a template for how seabed survey data is delivered to and managed by Oil and Gas companies. It includes a structure for data and information related to:

- Sweep/debris survey
- Site survey
- Pipeline route survey

Figure 32 shows the different elements that are managed by the SSDM.

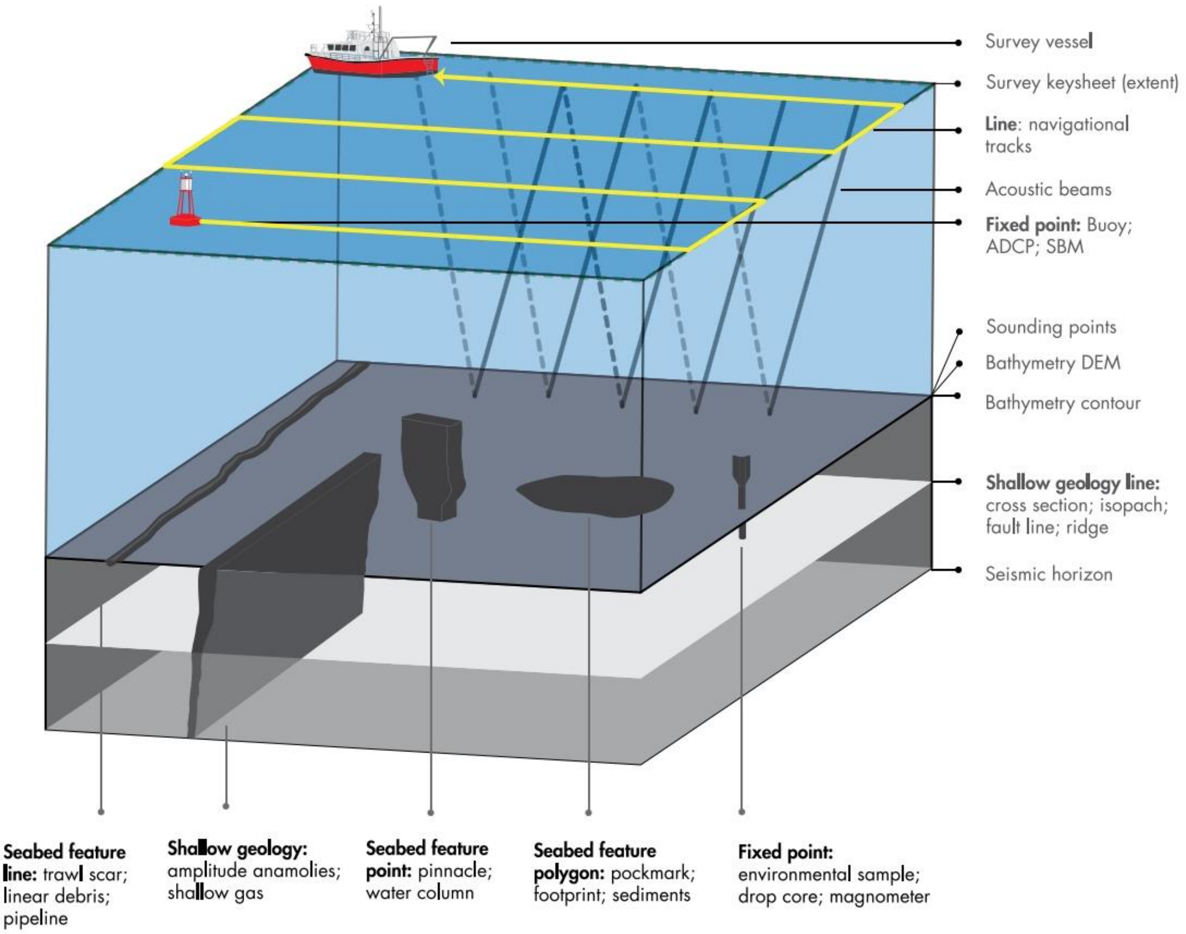


Figure 32: SSDM overview of elements; taken from (OGP, 2013)

Objectives in the development of the data model were:

- Provide a structured workflow for managing survey data
- Model hydrographic, shallow geophysical hazards and geotechnical features acquired by offshore surveys
- Model the survey navigation and project details for each survey job
- Provide flexibility for optional extension and compatibility with Infrastructure/Installation Data Model (e.g. APDM)

This Seabed Survey Data Model should be a well suited tool to handle the data involved in the surveys for pipeline integrity. However, information on an actual pipeline or pipeline facility is not part of the SSDM. The optional extension and compatibility with infrastructure/installation data models has not yet been developed. As such, a gap exists for crucial information on the relation between observed (sub)seabed features and the pipeline or pipeline facilities. This thesis research intends to bridge this gap, not by including the infrastructure data in the SSDM, but by relating the SSDM with an existing pipeline data model. Some work has already been done for this issue, see (OGP, 2013).

The SSDM not only models the data itself, but also the survey project details. This provides a lot of essential metadata that is required for a thorough assessment of the data deliverables and for the storage and management of project data.

The conceptual model of the SSDM Survey Measurements Classes is presented in Figure 33.

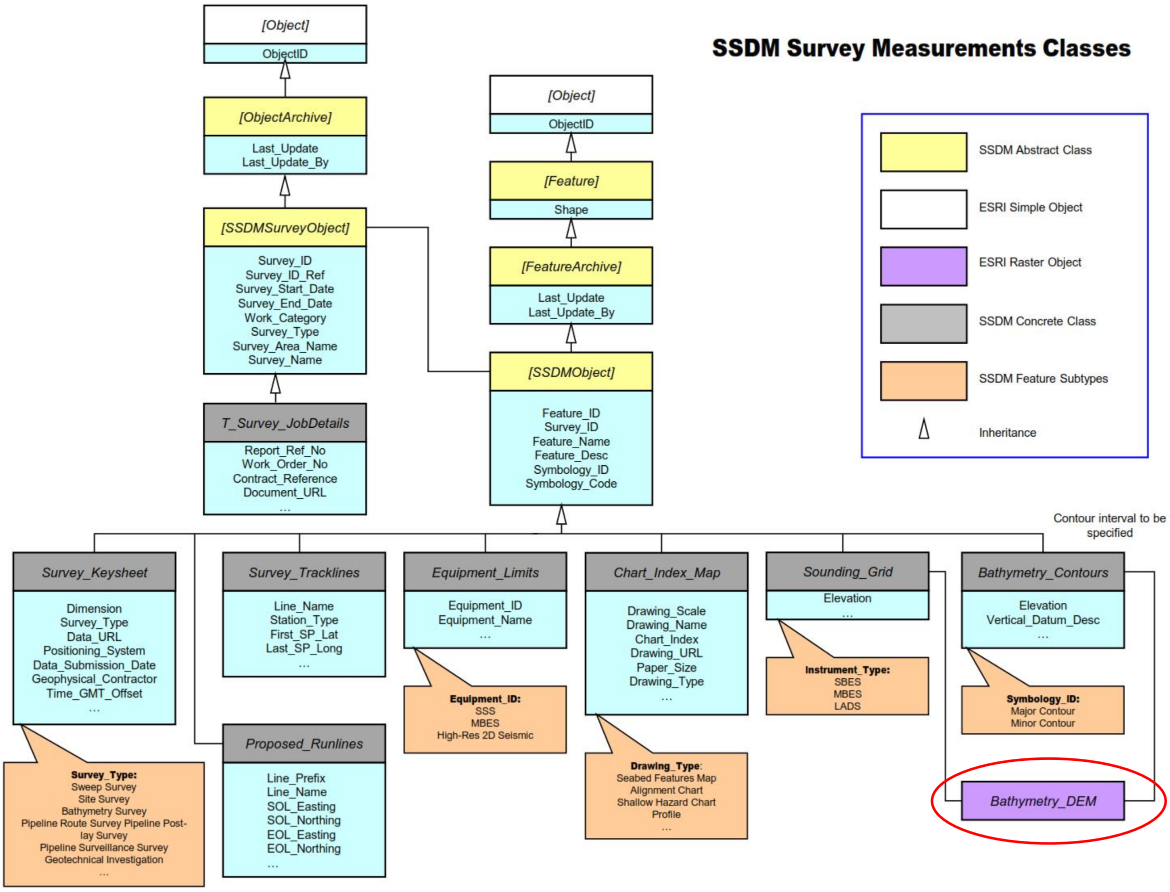


Figure 33: Conceptual model of SSDM Survey Measurements classes; taken from the SSDM V1_2014 package materials

For the development of the pipeline integrity SDI the Bathymetry_DEM ESRI Raster Object is one of the major data sources. The raster is related in the model with the class 'Sounding_Grid'. This relation was explained in section 3.3.

5.3. Combining the standards

The next step would be to combine the different standards and models with each other. This should be done on an abstract conceptual level. Then, the implementation in a technical model should be done. For an example for the conversion of a conceptual model to a technical model, the Malaysian LADM country profile for the ISO 19152 standard can be taken, see (Zulkifli, et al., 2014). Finally the data from the existing sources should be transformed through model to model mapping.

After consulting all described standards, it has to be concluded that the standardization environment is very diverse. For this thesis research is has proven to be very complicated to integrate the various standards on a conceptual level. The geographic data standards on the one hand and the pipeline integrity management standards on the other, hardly have any common ground. Data issues are almost completely neglected in the pipeline integrity standards, let alone spatial data.

The PODS and SSDM standards do focus on the data and also deal with spatial data. Where the PODS provides an ERD and the SSDM a conceptual model that is not strictly a conceptual model since it is already implemented in ESRI ArcGIS, reverse engineering of these models is required if they are to be used in the SDI. An attempt is done for this reverse engineering.

Where different standards have developed different data models, a common ground needs to be found to make it possible to combine the models. As was already indicated in section 2.3, on two levels a gap is identified:

1. Basic schemas for geographical information as defined in the ISO 19100 series are not used by the PODS, SSDM and ISO 15926 data standards. They have their own methods to describe the geometric properties of the data.

2. Some of the different standards relate to the same objects, but are not related to each other. For example, the INSPIRE application schema for Utility Networks defines how pipeline networks could be modeled. PODS does the same. However, they don’t share any attributes.

An extension of existing models with parts of other models is possible when the models are not about the same thing. In this case, the PODS model can be extended with geometry attributes of the ISO 19100 series. The classes ‘Station_Point’ and ‘Route’ get extended with the attributes GM_Point and GM_Linestring.

Model to model mapping is required to come to a common ground if the models are about the same thing, but use a different language. This is the case for INSPIRE application schema for Utility and Government Services and PODS. However, it is not deemed added value to have the INSPIRE standard implemented in the company.

5.4. Final model

For the model of this research, first existing industry standards were considered. It appeared that although these standards got the data, it was not possible to come to integrated use. Extension with attributes of general geometry standards are necessary. Application domains of the standards are consulted, but not deemed added value for the company.

The final model is mainly based on reverse engineering in UML from existing and at the company implemented databases models. As a constant in the geographic information standards was the reference to the ISO 19100 series. Elements from this standard are therefor included in the final conceptual model for the pipeline integrity management SDI as presented in Figure 34 (rotated to aid readability).

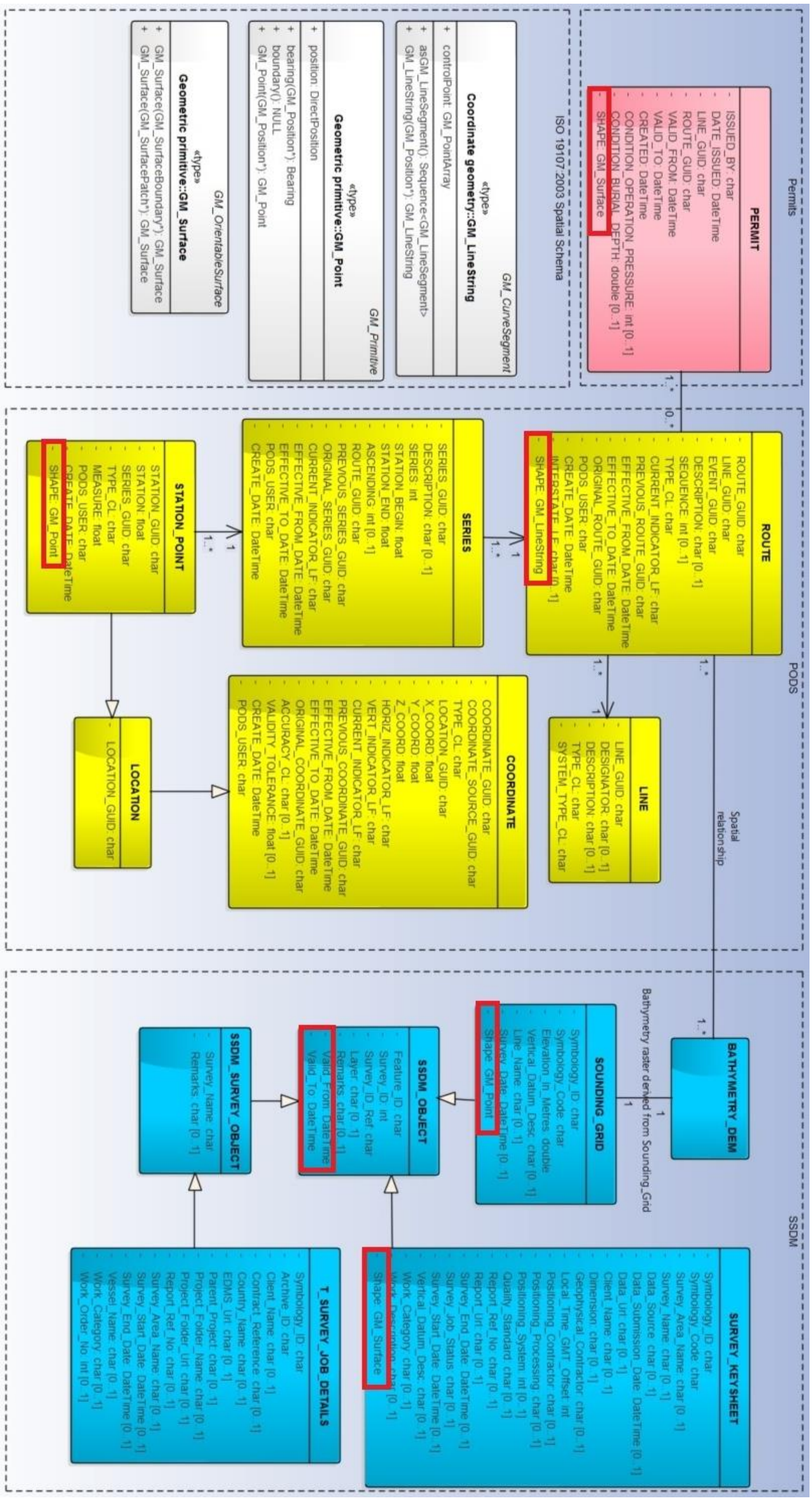


Figure 34: Model for pipeline integrity management SDI

The model shows three main parts, one for each of the data sources. Pipelines (PODS), Seabed (SSDM) and permits. Added are also the ISO classes for geometry that are used for the extension of the existing models.

As no conceptual model is available for the PODS, the main tables that define the pipeline centerline are selected from the physical data model for the conceptual model. A shape attribute is added in the ‘Route’ and the ‘Station_Point’ classes to enable compliance with ISO/TC211. It can be suggested that the table ‘Location’ can be taken out. However, since this is already implemented at the company, chosen is to stay as close to the implemented data structure as possible. Taking out a table that obviously plays a role in the database does not seem viable.

For the seabed part, a so-called conceptual model of the SSDM is available, but this is already implemented in ESRI ArcGIS geodatabases. Also for this part of the conceptual model, some reverse engineering had to be performed. Shape attributes have been added for compliance with ISO/TC211 in the classes ‘Sounding_Grid’ and ‘Survey_Keysheet’. For temporal consistency the attributes Valid_From and Valid_To are added to the class ‘SSDM_Object’. As all the other classes inherit from this class, the Valid_From and Valid_To attributes are valid for all the classes in this part of the conceptual model.

For the permits part, a concept is made that is based on permits for individual pipelines. Also here, a shape attribute has been added for the compliance with ISO/TC211. In section D.3, also permit data was mentioned in relation to maximal allowable free span and risk based integrity management. Due to time constraints, these had to be omitted in the final conceptual model. It is recommended for further studies to include these data sources.

The attributes ‘Condition_Operating_Pressure’ and ‘Condition_Burial_Depth’ are the values as established in the permit for construction, based on the design appraisal (see section A.4). It is recommended that links to the actual documents containing this information will be established in a later stage, when the document repository containing the documents is sorted out in the company.

6. Proof of concept

The final step of the research is to apply the conceptual model in the real life situation of the company with actual data. Test data as described in section 3.3 is made available for this. First the used data is briefly discussed, next the data is applied in the use cases as introduced in section 3.4. Finally the results are briefly discussed.

6.1. Used data

In this test case, the 3D centerline for the GP-001 pipeline is used. This pipeline transports gas produced at platform L10-B to platform L10-AP. Two associated raster layers from the SSDM are used for the bathymetry. The data was acquired during the 2013 and 2014 survey campaigns. Also added is the feature class Burial_Requirements. See Figure 35 for a screenshot of the data combined in an ESRI ArcMap document.

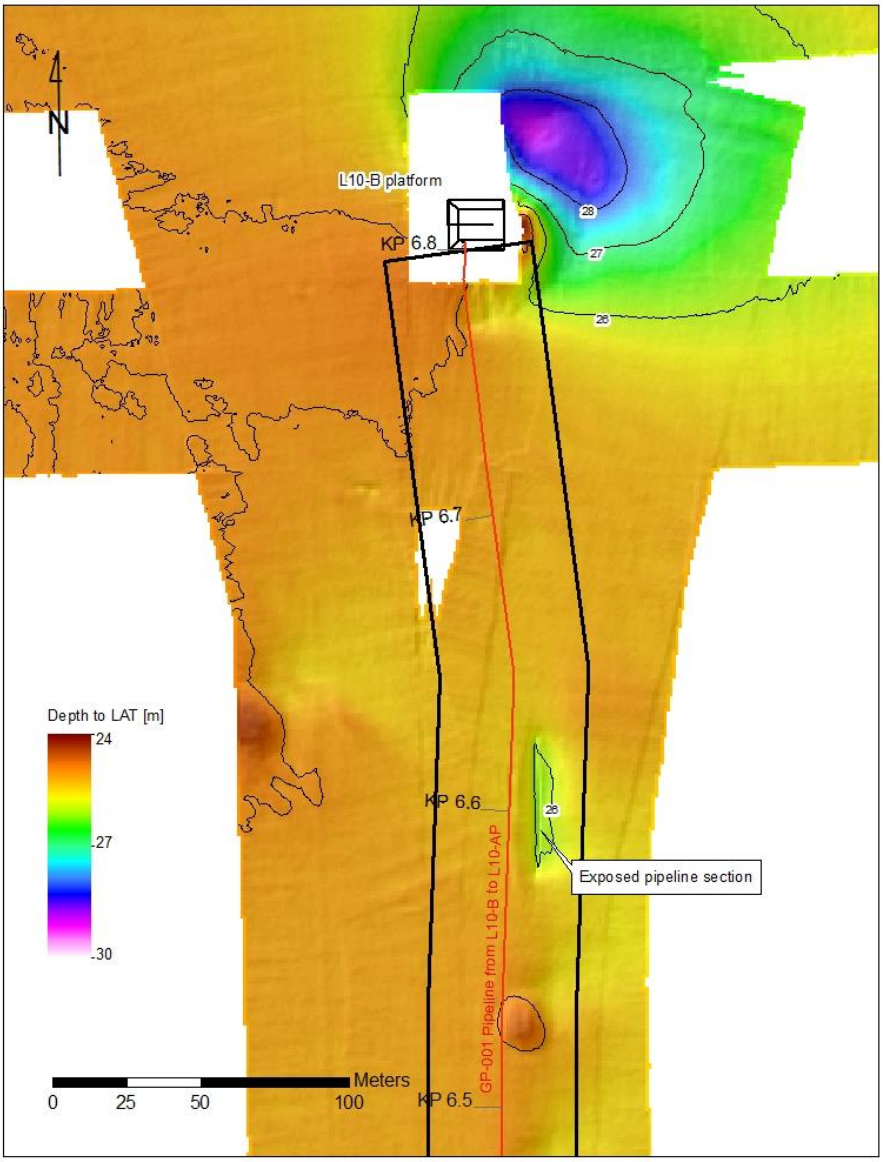


Figure 35: Example of combined pipeline, raster and permit data

The same data, in ESRI ArcScene is presented in Figure 36.

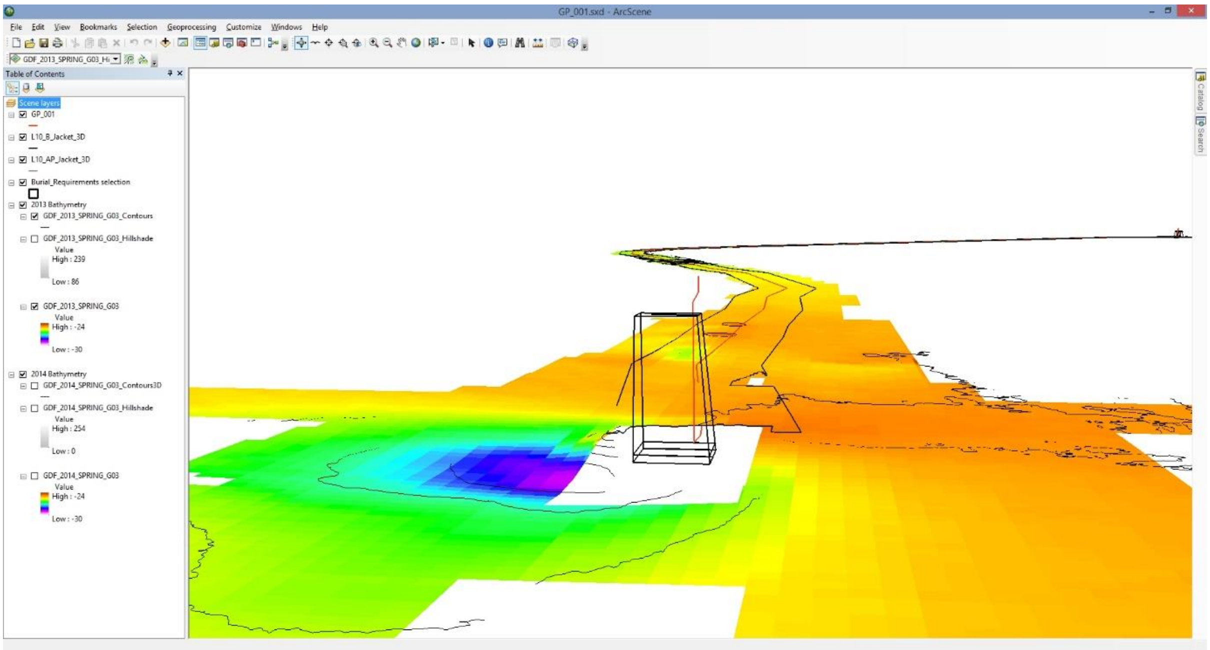


Figure 36: Example of combined pipeline, raster and permit data in ESRI ArcScene

As can be seen in the screenshots, the horizontal position of the pipeline doesn't line up with the locations where in the exposed pipeline section is identified in the bathymetry dataset. This might compromise the results of the use cases. Because this is an old pipeline (installation date is 1984), the reason for the different positions can be that the 3D centerline is based on old centerline data. It is recommended that as-found positions during the survey are used to update the 3D centerline. See annexes IV and V for the involved workflows.

6.2. Use cases

Use case 1: Monitor dynamic seabed condition at known locations

From the 2013 survey results it is known that the seabed near the L10-B platform has changed because a pipeline section is found exposed.

The pipeline engineer has indicated that the GP-001 pipeline is found exposed from approximately KP 6.620 to KP 6.580. The survey engineer selects the bathymetry datasets and 3D centerline, and by overlaying these data resources he should notice the non-conformity. But, alas, from the resulting image, no non-conformity can directly be ascertained. The 2013 bathymetry data however, shows the exposed pipeline clearly.

By overlaying the 2014 bathymetry an analysis can be performed of what has happened with the seabed in the meantime. Different tools can be used for this, such as raster calculation (e.g. difference, minus). See Figure 37 for an example of such an analysis.

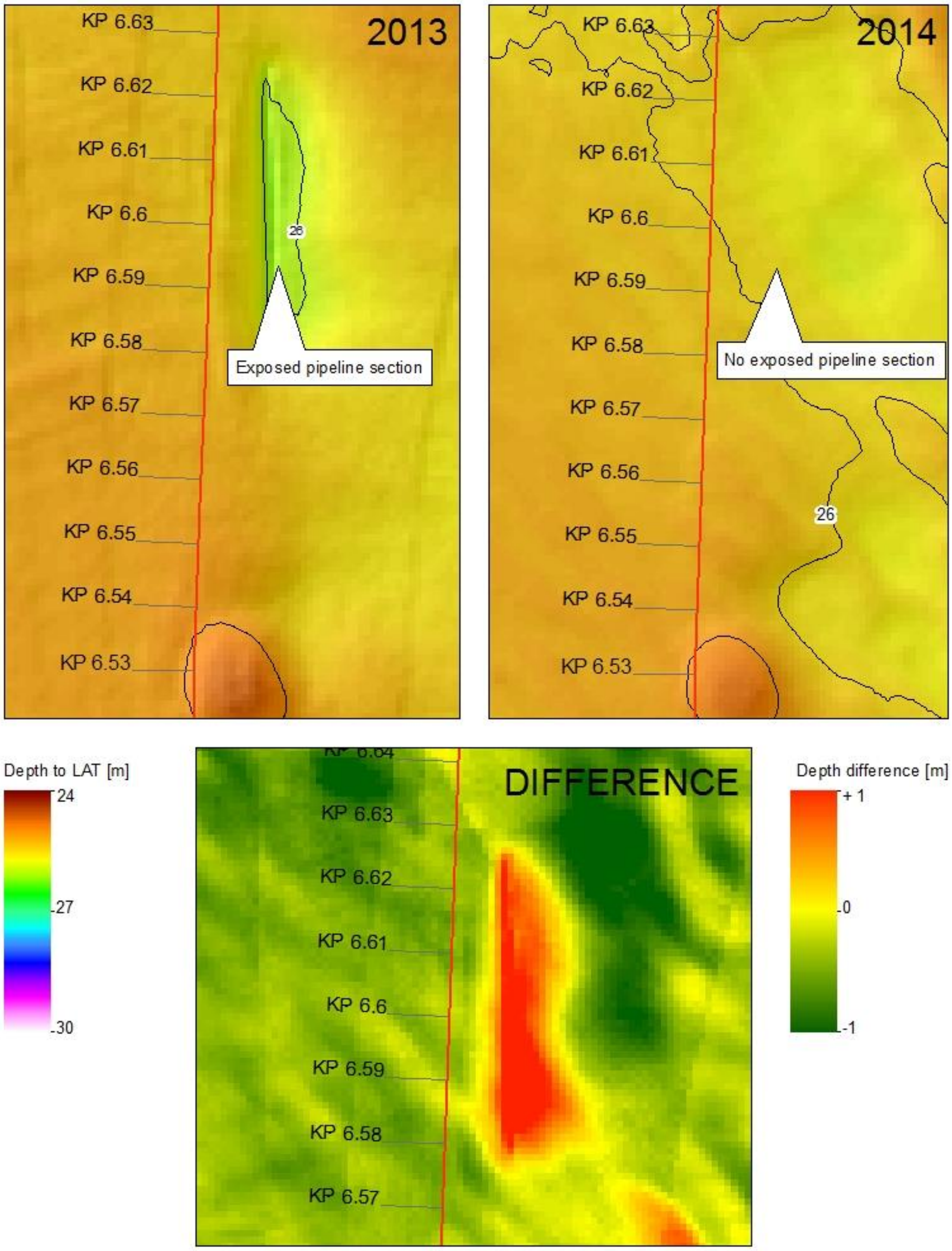


Figure 37: Result of use case 1 data analysis

With a picture like this, the Marine Surveyor can inform the Pipeline Manager about the changes of the seabed in between two survey campaigns. It seems like the hole has been filled up again with sediments. Off course, with more datasets available, different periods can be compared and trends might be discovered. However, as stated before, interpretation of the nature of the seabed dynamics is work for a specialist. It can be concluded that the SDI can provide the input data and information to start thorough analysis of the local dynamics of the seabed.

Use case 2: Find non-complying pipeline sections

The second use case was defined to test whether the SDI can provide the data to do analysis of compliance of pipeline sections with permits.

In this case, the Pipeline Engineer selects a pipeline that he wants to check. The 3D geometry of this pipeline is then laid over the most recent bathymetry dataset by the Marine Surveyor. Next, two pipeline profiles are created: one based on the 3D geometry of the centerline, the other based on the horizontal position of the centerline, but with the elevation values of the seabed. The difference between the two profiles should be at least the value that is stated in the permit. For an example of the result see Figure 38.

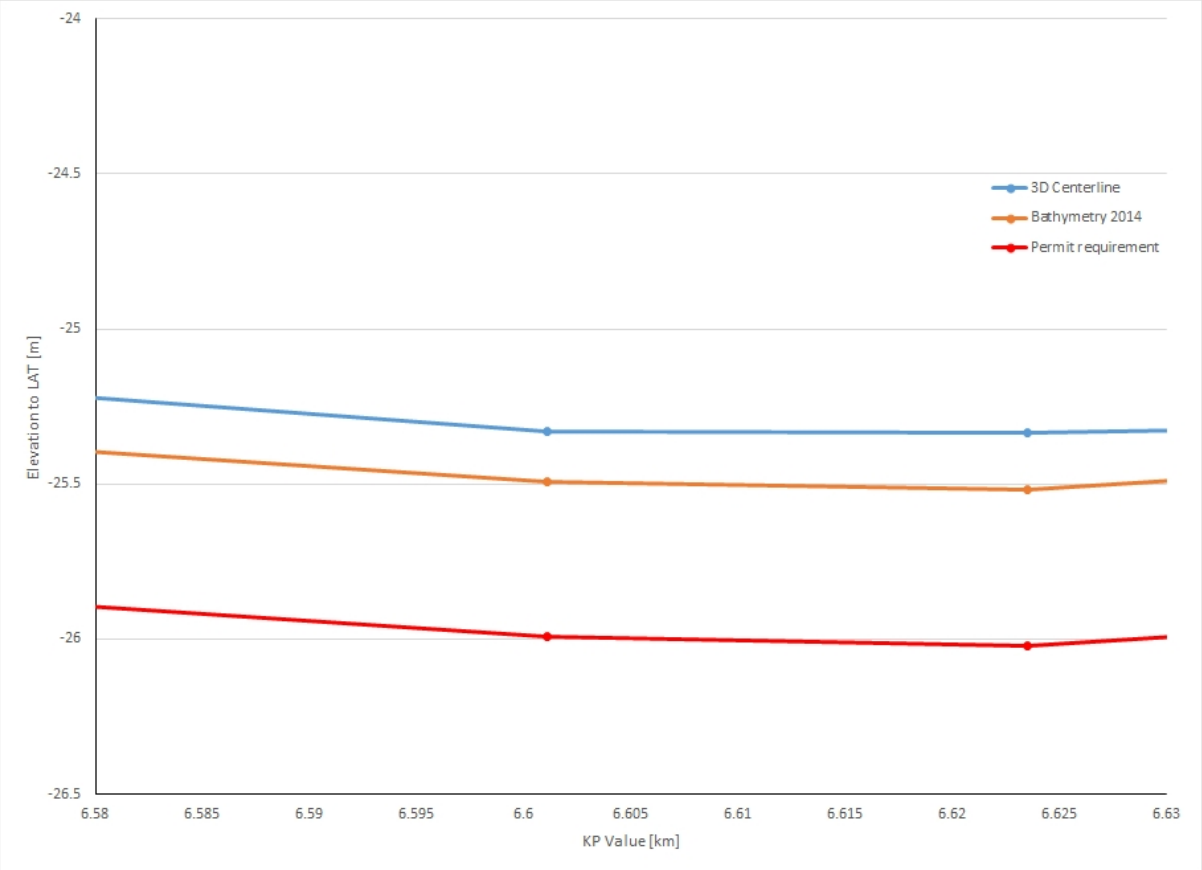


Figure 38: Result of use case 2 data analysis

The two profiles are displayed in one graph and a third profile is added: the permit requirement. This example shows that over the whole section, the 3D centerline (blue line) is above the seabed (orange line), and, as a consequence, not conform permit requirements (red line). In fact, the whole centerline is not conform permit requirement. Generating a map based on this data will not provide any information, however, it gives insight in the data requirements of the SDI.

In this use case, the data needed for the analysis was provided by the SDI. However, as noted before, the 3D centerline doesn’t match as-found positions of the pipeline. Moreover, during the creation of the 3D centerline, no actual elevation data was available. The 3D centerline got interpolated over the bathymetry of 2013 for elevations. Where the SDI is actually providing the requested data, the quality of the data is not sufficient. Recommended is that in further developments, data quality issues will get proper attention.

Additional use case: Risk based pipeline integrity management

The second use case can be extended by using different permit requirements. As discussed in sections 2.3 and 3.3, a future development is risk bases integrity management. By using the described Hazard Zone data source for defining sections of the pipeline that require different standards, the permit and the inspection and survey program might be renewed.

By a linear referencing overlay operation the centerline geometry data is combined with the identified Hazard Zones. A resulting table (see Table 3) containing sections with specific requirements is created, based on hazard zones that have been identified as potential risks for the pipeline network. See Figure 39 for a map indicating both the non-conformity and the hazard zones.

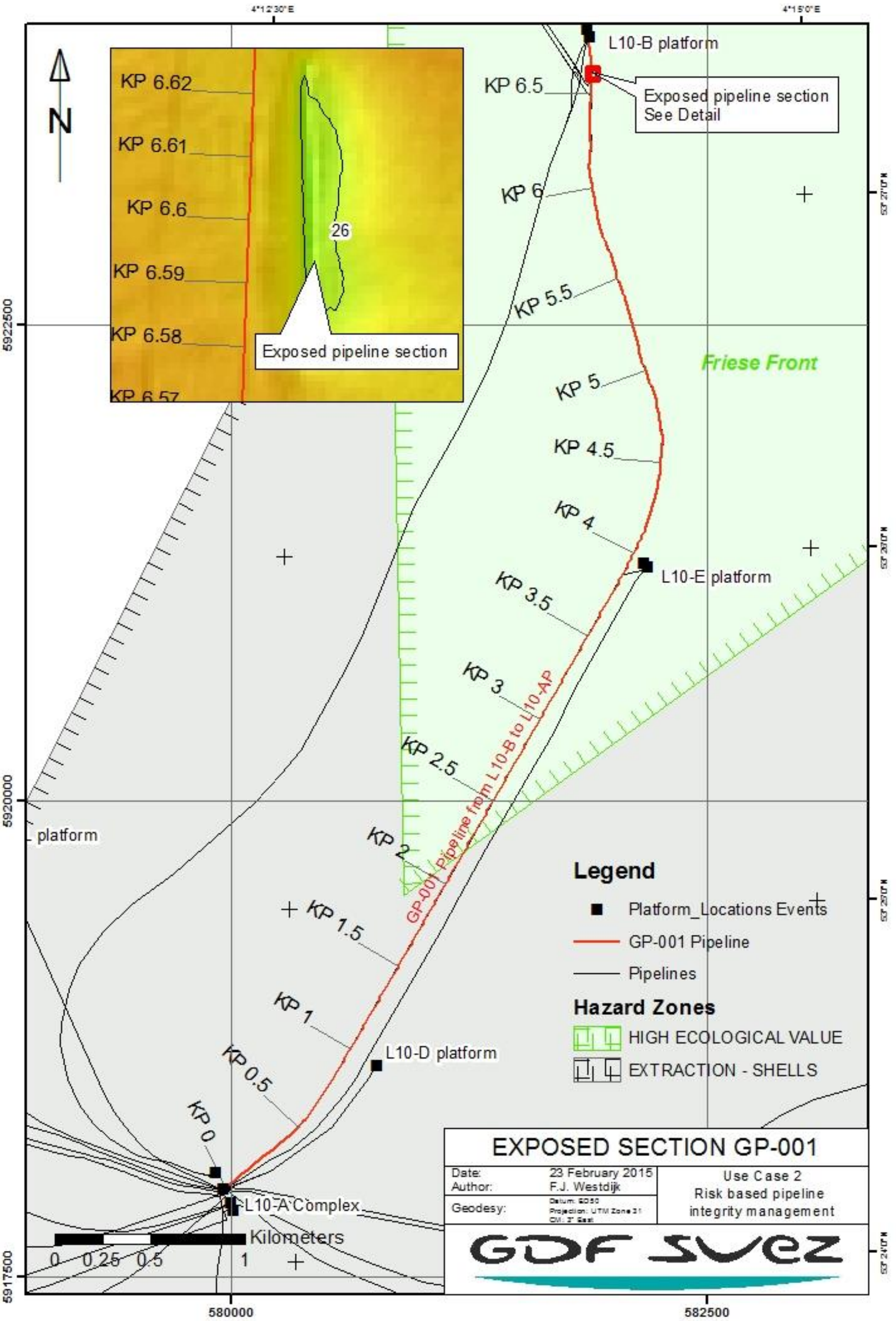


Figure 39: Result of use case 2 data analysis in combination with Risk based pipeline integrity management

This map shows that for a large part the GP-001 pipeline route lies within an area of high ecological value – Friese Front. Moreover, the whole pipeline lies within an area where extraction of shells is allowed.

Table 3 shows the details of the intersection of GP-001 pipeline sections with the hazard zones.

FID	LINE_GUID	ROUTE_GUID	FROM_KP	TO_KP	Naam	Accessibil	Source	SHAPE_Leng	SHAPE_Area	NAME	TYPE	TYPEGEBIED	NAAMGEBIED	BEHEERDER	LAST_UPDAT	ID
1	GDF	GP-001	2.190	6.833	Friese Front		RWS DNZ geb bijz ecologisch wrd	249351	2880610803		ENVIRONMENTAL - HIGH ECOLOGICAL VALUE	4		OSPAR	8/1/2012	1308
2	GDF	GP-001	-0.047	6.833	OVN		RWS DNZ Wingebieden	967432	16170986311		EXTRACTION - SHELLS	Commercieel	OVN	Vergund - 2 -Geen maximum	8/1/2012	0
3	GDF	GP-001	-0.047	6.833	Netherlands		FUGRO Gas & Oil Map - nations	1934478	99522490062	Netherlands	POLITICAL - NATIONS				8/1/2012	0

Table 3: Risk based pipeline integrity management example

As can be seen in Table 3 and Figure 39, the exposure of the GP-001 pipeline lies within the area of the Friese Front. Based on this information, the pipeline manager might decide on swift action to remedy the situation, since an incident with the pipeline in such an area would have drastic consequence on the environment.

Furthermore, it can be decided that for the whole of the pipeline section from KP 2.190 to KP 6.833, a different inspection and survey regime has to be implemented, because the section lies within the Friese Front area.

7. Conclusion and recommendations

This concluding chapter will finalize the research by presenting an answer for the research question, reflecting on the research steps and choices and by providing a list of recommendations for further research and implementation. Answers are given for the research question and sub-questions in section 7.1. Section 7.2 deals with issues that were encountered during this research, in the form or reflections. Finally, section 7.3 sums up recommended points of action for further research.

7.1. Answering the research question and sub-questions

In the introduction of this MSc GIMS thesis research report the research question was defined as:

> ***How to realize integrated use of heterogeneous offshore pipeline integrity data resources to support pipeline integrity management throughout full life cycle of the offshore pipeline object, according to SDI principles?***

In this concluding chapter, this question gets answered by answering the sub-questions.

Sub-question 1: What is the full life-cycle of an offshore pipeline and what stages in that life cycle-can be identified?

A life-cycle describes the existence of an object from begin to end. For a pipeline four (4) main stages in the life-cycle have been identified:

1. Design (including obtaining permits)
2. Construction
3. Operations & Maintenance
4. Abandonment

Sub-question 2: What actors, processes and heterogeneous data sources are involved in offshore pipeline integrity management?

Decided was to focus on offshore pipeline integrity management during the Operations & Maintenance stage of the life-cycle of a pipeline.

Thirteen (13) processes, involving eight (8) actors, using three (3) data sources are identified in offshore pipeline integrity management. The context of these processes, actors and data sources is the corporate environment of the company, where no policies regarding geographical data exchange are formalized, and no access network exists that is specifically designed for the exchange of geographical data. The data is stored at two different locations: pipeline data in the PODS database at the pipelines group, seabed data in the ESRI geodatabase of the survey group. For permit information only the documents were stored. However, the documents are not stored centrally accessible.

Sub-question 3: What are SDI principles and how can they be applied in the context of this research?

The main SDI principle is interoperability of data. From a technical data management perspective, semantic interoperability is the key feature of a SDI. When a real-life object gets represented in a computer database, its characteristics are stored. Ontologies contain the definition of the modeled object and its characteristics. When these ontologies are shared, different models can be connected to each other and data is interoperable.

Sub-question 4: What methods and standards for data modelling for the pipeline object, seabed data and permit information can be used in the research context and how can they be integrated?

A hierarchy of standards exist that can provide the semantic interoperability that is part of the conclusion of sub-question 3. Starting from internationally accepted standards for geographical information (ISO 19100 series), the main building blocks are transferred to different levels of standards: the INSPIRE directive generic model for Europe, the NEN 3610 standards for the Netherlands. All these standards use the same main vocabulary. They are also extended with specific application domain schemas.

For this research, The INSPIRE directive application schemas for Area Management/Restriction/Regulation Zones and Reporting Units (Permit information), Elevation (Seabed data) and Utility And Government Services (Pipeline) are applicable. The NEN 3610 standard refers to the IMKL model for an application schema for pipeline networks. The IMKL in turn refers to the INSPIRE directive for network facilities. This is not considered further in this research, since network modelling is not part of the scope. For permits, ISO 19152, the standard for LADM might be applicable.

Next to the geographical data standards, also industry data standards are applicable to the research content. Very soon in the research process, a gap was identified between the industry data standards and the geographical data standards and their application schemas. While the standards are content wise overlapping, no shared concepts and languages exist to describe the data. In other words, the standards and their models are not semantically interoperable.

One solution is to extend one of the models with attributes of the other. This has been done with the PODS model, where basic geometry types have been added. Another solution is model to model mapping using (on-the-fly) data transformation tools. By doing this, the models can be integrated, and integrated data use can be achieved.

Sub-question 5: How can an integrated data model be tested and assessed?

By applying the data to the use cases, the functionality of the model is tested. Iterative sessions might help to improve the data model and developing new use case might result in an extension of the model.

The final conclusion to the research question is that through semantical interoperability and standardization, data models for different domains can be integrated and integrated data use can be achieved. When two not related models are to be integrated, extending one of the models with attributes from the other model results in interoperability of both models. Another suggestion that has not been tested in this research is model mapping through on-the-fly transformation. This applies when two different models deal with the same objects, but in different terms.

7.2. Reflections

Technology is not the only issue. It's the awareness, recognition and willingness of key decision makers in the company that is the starting point for the implementation of a SDI. The concept of SDI must get institutionalized. Only then will actual companywide integration of heterogeneous data sources for no matter what business process through no matter what technical solutions be realistically possible. This consists of various components, of which the definition and implementation of company policies regarding geographic information management and the adherence to (international) geographic information standards are the most important ones.

Institutional integration

The main conclusion of this research is that a SDI can become the nerve system of the company - the main infrastructure for all data and information management processes - if semantic interoperability is achieved. From a company management perspective awareness of the pervasiveness of the SDI concept must exist and the importance of standardization must be recognized, before this can happen. For the industry as a whole, this awareness and recognition should result in extending existing data models with the ontologies of the internationally accepted standards for geographical information.

The organizational context is key in integrating heterogeneous data resources where SDI as a concept must get institutionalized: "*What is clear [...] is that if countries or jurisdictions are to take advantage of the spatial information revolution and the SDI concept, then major institutional changes are most probably required in government, in professional bodies, in higher education and in the private sector.*" (Williamson, Rajabifard, & Feeney, 2003, p. 11)

This observation can be supported by evidence from this research, where a huge gap is identified between the application schemas of international geographic information standards on the one hand (INSPIRE annexes) and industry data standards (PODS, SSDM) on the other hand. If company management does not invest in the development of (geographic) information exchange policies, it will be at the mercy of individual software vendors. By stating demands as key stakeholder, industry standard organizations are forcing to take the next step in standardization: comply with international geographic information and service standards. From a data exchange point of view, the relation with the outside world should always be open. Standards are a means to achieve this openness. Pipeline integrity management standards hardly mention data standardization.

At the company, the enterprise architecture must be defined with interoperability of systems as starting point. By using data and service standards, the architecture can remain flexible and open for new connections and components. An organic growth of the company SDI can then take shape. First the inter-organization infrastructure should be arranged, so that in a later stage intra-organizational information exchange can take place. These are developments that require a long term planning.

For the company, the GOIMS standard, and for this research the PIMS standard, is the overall policy for integrity management. Either an update of the GOIMS standard or an additional bridging document between international data standards and the company policies is required for the institutional change to take place.

As the company is developing a management system, recognition of the crucial role the information infrastructure has within the company, should be getting clear. It is hoped that with this research, awareness of the possible role of the SDI in the management system will grow. This research shows that it should be a top priority.

If the institutional integration reaches a tipping point, questions will arise like:

- How much and which part of the information and data that is not spatially enabled should be made spatially enabled?
- Which other data sources should be made available through the SDI? As other data sources have already been mentioned:
    - Production data (volumes, pressures, compositions, inhibitor injection etc.)
    - SCADA data
    - Visual pipeline inspection data (ROV, Dive)
    - Maintenance data
    - Legal data (Proximity/crossing agreements)
    - Other survey data: Pipeline route survey (Geotechnical data, Pipeline pre-lay survey, Pipeline as-built survey
- The role of SDIs in enterprise interoperability needs to be defined, particularly the spatial nature of information and data: is it just one of the many aspects of object information, or should it be the structuring principle of the data? If the latter, what is the reason for the special status of spatial characteristics? Is there a fundamental reason to support this?
- How should a SDI be related with the ISO 15926 standard?

Standardization

During the research, standardization was recognized as an important aspect. However, how to actually deal with it, was not very clear. The documentation of the geographical information standards was very detailed and without proper experience, it turned out very challenging to translate the standard descriptions to actual data. The industry standards, however, turned out to be fully hands-on, without proper descriptions. The huge gap between these, has proven to be a big challenge.

There are a lot of different standards. Sometimes even different ones for one and the same thing. How to choose between the standards is not easy. As indicated in sections 2.3 and 5.2, the standards can be seen to form a hierarchy. For geographic information and services, the ISO 19100 series standard is the top of the hierarchy. All standards below should follow the ISO – INSPIRE, NEN 3610 etc. The concept is not difficult to understand, but the actual implementation is quite complex. The required technical knowledge for implementing the standards is really specialized and the language to deal with the matter is quite extraordinary for someone who is not used to work with it.

The language does not easily resonate with 'domain experts', in this case for the domain of pipeline integrity management and marine surveying. As an example, hardly any reference to external standardization efforts for data management is made in the PODS database model documentation. It is developed for one purpose and one purpose only. It is understood that it would greatly enhance the data model if it made interoperable with other domain standards. Now it stores the data under its own definitions and the relation with 'the outside world' seems to be nihil. This makes the model rigid. As a solution in this research, attributes are added to classes in the model. How this actually translates in the physical database is not clear at all.

It is hoped that the development of the Pipeline_ML might solve this issue.

Reverse engineering using UML

What a conceptual model should entail exactly, seems to vary widely. The PODS standard does not provide a conceptual model, it just works with an Entity Relationship Diagram (ERD) for the database. The SSDM standard provides a conceptual model that is already implemented in a specific database. Reverse engineering these model has proven to be a difficult exercise.

It seems that UML is used in two main different ways: 1. Database design (PODS, SSDM), 2. Abstraction of reality (INSPIRE). When it's used in the first way, the physical database tables are actually put in UML. When it's used in the second way, no direct relation with a (eventual) physical database is directly seen.

During the research it turned out that due to the unfamiliarity with actual physical databases on the one hand and a rudimentary understanding of the UML language on the other, creating a conceptual model while doing reverse engineering was quite a challenge. It wasn't helpful that UML was used in different ways in the existing standards.

Reconstructing the conceptual model based on the identified INSPIRE application schema, the NEN 3610 Measurement model and the future Pipeline_ML would be a good first step in refining the proposed model. The next step would be to actually harmonize datafields on-the-fly between the existing data and applications via the conceptual model. For example: During the research it was decided to use an example dataset for pipelines, instead of reading directly from the PODS database. GUIDS in the classes are actually database specific fields. For convenience sake, the value for the attribute 'description' is used in the example dataset by manual manipulation. Using harmonization, this might have been coded as one of the translations, without having to do manual manipulation at all.

Data quality

As can be concluded by the second use case, a method to check the data quality needs to be included in the SDI. The horizontal position of the pipeline doesn't line up with the locations where the exposed pipeline section is identified in the bathymetry dataset. This strongly compromised the results of use case 2.

Two methods for controlling data quality are topology and defining database constraints. However, even with these methods, the data quality issue that was encountered would not be solved. This concerns the base data of the system. In a quick search, no suitable methods have been found to manage this. Manual editing and human interpretation are still necessary.

7.3. List of recommendations

During the writing of this report, recommendations were given. Below ten of these recommendations are summed up and briefly explained. It concerns recommendations for further study and recommendations for the company if actual SDI development is planned based on this thesis research.

1. Refine the data model and harmonize it with INSPIRE application schemas for elevation and permits. The PODS database got extended with attributes from the ISO 19100 series. The seabed survey database, is already implemented in ESRI. For the conceptual model, relations with INSPIRE can be defined. The SSDM model can then also be used in different environments. The permit information can be modelled after the ISO 19152 LADM standard.
2. Report to PODS that the extension of the data model is required for compliance with ISO standards for geographical information.

3. At the moment, there is no evidence in the literature of integration of SDI principles in enterprise architecture and enterprise interoperability. This could be a research topic.
4. The Dutch IMKL seems to be outdated. Efforts to make use of attributes of NEN 3610 should result in a better model.
5. Other data sources in the company might be considered for future developments at the implementation of a SDI. These data sources might include:
    - Production data (volumes, pressures, compositions, inhibitor injection etc.)
    - SCADA data
    - Visual pipeline inspection data (ROV, Dive)
    - Maintenance data
    - Legal data (Proximity/crossing agreements)
    - Other survey data: Pipeline route survey (Geotechnical data, Pipeline pre-lay survey, Pipeline as-built survey)
6. Consider a companywide strategy including Enterprise Architecture, SDI development and ISO 15926 implementation in a joint project
7. When an extended version of the SDI would be implemented at the company, modelling the pipelines as network objects conform the INSPIRE General Network Model might help to include extended functionality.
8. The company should invest in making the permit data for pipeline available through the company's network.
9. For the creation of 3D centerlines, horizontal and vertical position accuracy standards must be defined. As could be seen in the second use case, the data wasn't accurate enough for the required analysis.
10. Find a method to control data quality and lineage. The reliability of data depends largely on what is known about the data. For all datasets this metadata needs to be created, structured and maintained.

Bibliography

Chen, D., Doumeingts, G., & Vernadat, F. (2008). Architectures for enterprise integration and interoperability: Past, present and future. *Computers in Industry, 59*(2008), 647-659.

Fiatech. (2011). *An Introduction to ISO 15296.* Fiatech.

GDF SUEZ. (2011). *Development Process, Part 1 (internal policy document).*

GDF SUEZ. (2012). *GOIMS GDF SUEZ E&P Operational Integrity Management Standard (internal policy document).*

GDF SUEZ. (2013). *GDF SUEZ EPI Pipeline Integrity Management Standard (internal policy document).*

GDF SUEZ. (2014). *GDF SUEZ EPI Pipeline Integrity Management Standard (internal policy document).*

Goodchild, M., Egenhofer, M., & Fegeas, R. (1997). Interoperating GISs: Report of a Specialist Meeting held under the Auspices of the VARENIUS Project. *VARENIUS.* Santa Barbara.

Grus, L. (2010). *Assessing Spatial Data Infrastructures (Phd-thesis).* Wageningen: Wageningen University.

INSPIRE. (2008). *Definitin of Annex Themes and Scope; D.2.3.*

INSPIRE. (2013). *Data Specification on Utility and Government Services; Reference: D2.8.III.6_v3.0.*

Jardim-Goncalves, R., Grilo, A., & Agostinho, C. (2012). Interoperability Body of Knowledge: the Genesis for the Enterprise Interoperability Science. In *Enterprise Interoperability: I-ESA '12 Proceedings* (pp. 351-357). ISTE Ltd.

Manso, M.-A., Bernabe, M.-A., & Wachowicz, M. (2009). Towards an Integrated model of interoperability for Spatial Data Infrastructures. *Transactions in GIS, 13*(1), 43-67.

Moen, W. (2012). Information Retrieval Protocols: Z39.50 and Search & Retrieve via URL. In M. J. Bates (Ed.), *Understanding Information Retrieval Systems: Management, Types, and Standards.* Boca Raton: Taylor and Francis.

Nebert, D. D. (Ed.). (2004). *Developing Spatial Data Infrastructures: The SDI Cookbook* (2 ed.). GDSI - Global Spatial Data Infrastructure.

NEN 3656. (2014). *Eisen voor stalen buisleidingsystemen op zee.* NEN.

OGP. (2013). *Guidelines for the delivery of the Seabed Survey Data Model; Geomatics 462 series Data models note 2.*

Peters, D., & Richter, K.-F. (2008). Taking off to the Third Dimension - Schematization of Virtual Environments. *International Journal of Spatial Data Infrastructures Research, 2008*(3), 20-37.

PODS - Pipeline Open Data Standard. (2014, Oktober 23). Retrieved Oktober 23, 2014, from PODS: http://www.pods.org/

Rajabifard, A. (2008). A Spatial Data Infrastructure for a Spatially Enabled Government and Society. In J. Crompvoets, A. Rajabifard, B. v. Loenen, & T. D. Fernandez (Eds.), *A Multi-View Framework to Assess Spatial Data Infrastructures* (pp. 11-22). Wageningen: Space for Geo-Information (RGI), Wageningen University; Centre for SDIs and Land Administration, Department of Geomatics, The University of Melbourne.

Rix, J., Fast, S., Masser, I., Salgé, F., & Vico, F. (2011). Methodology to Describe, Analyse and Assess Subnational SDIs: Survey, Experiences and Lessons Learnt. *International Journal of Spatial Data Infrastructures Research, 2011*(6), 23-52.

Tisdale, J., Strahan, T., & De Lathouwer, B. (2014). *Charter for a SWG: PipelineML.*

Williamson, I. P., Rajabifard, A., & Feeney, M.-E. F. (Eds.). (2003). *Developing Spatial Data Infrastructures: From Concept to Reality*. London: Taylor & Francis.

Zulkifli, N. A., Rahman, A. A., Jamil, H., Hua, T. C., Choon, T. L., Seng, L. K., & Oosterom, P. v. (2014). Development of a Prototype for the Assessment of the Malaysian LADM Country Profile. *FIG Congress 2014 - Engaging the Challenges - Enhancing the Relevance,* (pp. 1-18). Kuala Lumpur.

Annexes

I. Organisational context

This GIMA (Geographical Information Management and Applications) thesis research will mainly be done at GDF SUEZ E&P Nederland B.V. offices in Zoetermeer, at the department of Engineering & Construction, survey and pipelines group. Professor and supervisor is Peter van Oosterom (TU Delft) and company mentor is Peter Baars (Asset Pipeline Systems Manager GDF SUEZ E&P Nederland B.V.). Coordinators are Sisi Zlatanova (TU Delft) and Frank Ostermann (University of Twente).

GIMA

The GIMA (Geographical Information Management and Applications) programme is a joined Master of Science (MSc) programme of Utrecht University (UU), Delft University of Technology (TU Delft), Wageningen UR (WUR), University of Twente (UTwente), offered by Utrecht University, Faculty of Geosciences, Graduate School of Geosciences, officially registered under the name Geographical Sciences[1].

GDF SUEZ group

GDF SUEZ E&P Nederland B.V. is an affiliate of the GDF SUEZ group that has its headquarters in Paris, France. The GDF SUEZ group is one of the largest energy companies in the world, with more than 147.000 employees worldwide, activities in close to 70 countries and a revenue of 81.3 billion Euros in 2013. The Groups activities are distributed in five operational branches, of which GDF SUEZ E&P Nederland B.V. is part of the Global Gas and LNG business line[2].

GDF SUEZ E&P Nederland B.V.

The affiliate GDF SUEZ E&P Nederland B.V has a history of 50 years of (offshore) operations in the Netherlands, first as Placid International Oil Ltd. (1964), Occidental Petroleum Corporation of Los Angeles (1995), TransCanada International (Netherlands) B.V. (1998), Gaz de France (GDF Production Nederland B.V. (ProNed) (2000), and now, since 2008 as GDF SUEZ E&P Nederland B.V.[3].

GDF SUEZ E&P Nederland B.V. is one of the largest operators in the Dutch sector of the North Sea, with more than thirty offshore production platforms, over 1200 km of pipelines and more than 300 employees. The core business processes are: exploration, development, production, commercial and abandonment[4]. The continuity of the organisation is ensured through exploration, takeovers and acquisition.

The departments of Exploration & Development, Engineering & Construction, Finance, Human resources, Legal, ICT, Purchasing, Commercial, Communications and General Affairs are located in Zoetermeer. The operations office, supply base and dock are located in

[1] For more information about MSc GIMA, see: http://www.msc-gima.nl/

[2] For more information about the organization of the GDF SUEZ group, see: http://www.gdfsuez.com/en/group/governance/operational-organization/

[3] For more information about the history of the organization of GDF SUEZ E&P Nederland B.V., see: http://www.gdfsuezep.nl/en/gdf-suez-ep-nederland-bv/who-are-we/history.html

[4] See DOP-DV-P-1000; Development Proces, Part 1 (2011); Internal GDF SUEZ document.

Den Helder; consisting of the departments of Drilling, Production, Logistics and Base and HSE. The staffing of the offshore production platforms is organised in Den Helder.

Pipelines group

The pipeline integrity group is a relatively young part of the organization. The main tasks of this group are the management of the integrity of pipelines and related assets, information management, compliance with standards and regulations and communications with the authorities. Furthermore, the pipelines group manages emergency response procedures, risk assessments, lifetime extension program and is consulted in case operations are planned and executed near the pipelines. Preventive and corrective maintenance of the pipeline system is partly arranged by the pipelines group.

Engineering & Construction department

The department of Engineering & Construction is responsible for the engineering and construction of new infrastructure and the modification of existing assets. Mechanical engineers, Structural engineers, Electrical engineers, Process engineers and Pipeline integrity engineers are involved in the day to day work, as well as many different contracted companies. The main work can be divided in:

- development of new projects
- modifications of existing production facilities or infrastructure
- pipeline integrity management

As supportive disciplines survey and drawing control are involved in all of these activities.

Survey engineers

The survey engineers are involved with the preparation, execution and processing of specific offshore operations, the conceptual route design of new developments and periodical acoustic inspections of the pipelines. Reporting to authorities on the conditions of the direct environment of pipelines is the main responsibility of the survey engineers. Each year (for some parts of the pipeline network even twice a year), the survey group organizes acoustic survey campaigns to ascertain seabed conditions along the pipeline routes.

Other Departments

Other departments at GDF SUEZ E&P Nederland B.V. are: Finance, Legal, ICT, Commercial, HSE, operations and base, and Production.

II. GOIMS 14 key elements

The 14 Key Elements Mandatory Requirements. Taken from (GDF SUEZ, 2012)

1 Leadership, Commitment and Accountability
Each GDF SUEZ Operations Leader shall ensure a single point of accountability for Operational Integrity Management and shall personally promote the adherence to and improvement of GOIMS within GDF SUEZ Operations.

2 Safe Operations
Each GDF SUEZ Operational Site Leader must ensure the reliability of safety barriers both technical and organizational have been implemented in line with the operational risk assessment. There must be a system in place for managing Safety Critical Equipment (SCE).

3 Risk Assessment and Management
GDF SUEZ Operations shall identify and mitigate operational integrity management hazards and risks. Risk assessments relating to operations safety will reflect the current state of risks.

4 Emergency Preparedness
GDF SUEZ Operations shall develop and maintain Crisis Management and Emergency Response (CM&ER) plans based on identified hazards and risk. These plans will be consistent with the group crisis management framework.

5 Integrity, Maintenance and Reliability
All GDF SUEZ Operations shall have processes in place to confirm that their facilities and equipment are fit for service. The aim being to avoid loss of primary containment and maintain structural integrity throughout the lifecycle of the facility and equipment in question.

6 Personnel Competency and Training
All GDF SUEZ Operations Managers must define the competencies needed for all positions in accordance with the Company standards and complying with minimum applicable statuary requirements.

7 Incident Management
Each GDF SUEZ Operation shall investigate all significant asset integrity incidents. Incidents of this type can be classified as:

- Major Incidents and High Potential Incidents,
- Uncontrolled releases,
- Unexpected failures of materials, equipment and structures,
- Accelerated rates of damage,
- Excursions outside safe design limits.

8 Environmental Stewardship
All GDF SUEZ Operations must evaluate the environmental impacts, aspects and issues specific to the area where GDF SUEZ operates assets.

9 Management of Change
All GDF SUEZ Operations shall maintain an MOC system to ensure continued integrity and safe operations in the event of temporary or permanent changes to technology, facilities, equipment, operations or organisation.

10 Information, Documentation and Effective Communication
All GDF SUEZ Operations shall ensure tha t practices and procedures are kept up to date

11 Compliance Assurance and Regulatory Advocacy
All GDF SUEZ Operations must demonstrate compliance with relevant statutory requirements and corporate policies

12 Engineering (Design), Construction, Installation, Operation, Maintenance, Assurance and Decommissioning
All GDF SUEZ Operations shall develop, maintain and use a set of Engineering Technical Practices in new design and construction, existing operations, modifications and decommissioning.

13 Contracted Services and Materials
All GDF SUEZ Contractors and Sub-Contractors competence and capability must be defined in the contracting process. A GDF SUEZ representative will be nominated and is responsible for ensuring that contract requirements are met.

14 Performance Assessment and Continuous Improvement
All GDF SUEZ Operation s shall have in place a performance management system. This shall include self and external assessments along with Leading and Lagging Key Performance Indicators (KPI's) and other metrics to measure the effectiveness of the Operational Integrity Management programs.

III. Pipeline route proposal geometry definition

A first concept of the pipeline route is created in ESRI ArcGIS as a polyline geodatabase feature class (possibly multiple lines for different options) related a point geodatabase class with route events, based on a given startpoint (usually a template of a platform at the site of an existing exploration well) and a given endpoint (usually an existing facility (platform), but can be also be a sidetap or landfall).

Restrictions and crossings with existing infrastructure along this route are inventoried and where necessary, circumvented. For this, reference data of Rijkswaterstaat, Hydrographic service, NLOG, FUGRO and other third parties is used.

Also practical considerations for the construction of the pipeline are already taken into account:

- The minimal length of the start-up of a pipeline before a bend
    - Although made from rigid steel, pipelines can be bent during pipelay. The bend radius is usually around 1500m. Depending on the material and diameter of the pipeline, the straight section of a pipeline before the first bend must be 800m up to 1500m, otherwise the straight section of the pipeline will not remain in the intended position when the pipelay vessel starts the maneuvering for a bend.
- The crossing angles with other pipelines and cables
    - This should not be smaller than 30°, otherwise the crossing constructions will get too big and expensive.
- The proximity of the pipeline route with existing platforms
    - Offshore platforms and drill rigs have a safety zone of 500m around the outer edge of the structure. The pipeline is not allowed to be laid within this safety zone, except when a tie-in at the platform is required.
    - In case of a tie-in at an existing platform, a pipelay vessel needs to be able to maneuver freely around the platform, without risking any collision. The minimum distance between the vessel and the platform is 20m.
    - In case of a tie-in at an existing platform, spools to connect the pipeline to the riser on the platform need to be designed. These spools allow the pipeline to extend when the operating temperature forces the steel to expand. The lay-down box of the pipeline head is chosen in such a way that the prefabricated spools can be fitted with the least amount of deviation from the design. Metrology results in the exact dimensions of the spools that will be adjusted accordingly to fit exactly.
- the location of (possible future) drilling rigs
    - at new and existing platforms the location where in the future a drilling rig will be positioned should remain well clear of pipelines. The minimum distance between the pipeline and the place where the outer edge of one of the legs of a drilling rig will be positioned, is 20m.
- In case of a landfall, the approach angle with the shoreline
    - This approach should be as perpendicular as possible

These considerations result in the polyline geodatabase featureclass (possibly multiple lines for different options) and points geodatabase featureclass drawn in ESRI ArcGIS, representing the intended pipeline route.

For linear referencing, KP values are calculated for all route event points along the route. This is done using the length along the line, consisting of the following points[1]:

- Startpoint (EP1)
  - Indicates the startpoint of the design pipeline route
  - KP 0.000
- Endpoint (EP2)
  - Indicates the endpoint of the design pipeline route
  - KP 0.000 + total length along the line
- Intersection point (IP1, IP2 etc)
  - Indicates a bend (arc) in the pipeline routing, including bend radius (typically 1500m)
  - Not on line, so no KP value
  - Only included when bends are required in the planned pipeline
- Tangent point (TP1a, TP1b, TP2a, TP2b etc)
  - Indicates the start (a) or end (b) of a bend (arc) along the line of the pipeline routing
  - KP 0.000 + length along the line
  - Only included when bends are required in the planned pipeline
- Crossing point (X-ing)
  - Indicates a crossing with existing infrastructure (cables, pipelines

[1] expressed in Eastings and Northings of the current coordinate reference system, which is European Datum 1950, UTM zone 31 N. This reference system is under discussion. Since February 2014, reporting of coordinates to the authorities is required to be done in ETRS89.

IV. 3D centerline creation workflow

The process of defining the 3D pipeline centerline looks different for old pipelines as opposed to new pipelines.

New pipelines

For new pipelines all as-built drawings and trenching data can be collected directly after the construction (see section B.2) and trenching (see section B.4) of a pipeline has completed. Combined with the metrology and as-built drawings of the spool pieces, upper and lower risers, the complete pipeline section as defined by the PIMS can be digitized, in case of the company in ESRI ArcGIS. The digitizing resolution of the trenching data is generally quite high: one point on every meter along the pipeline route. Many of company's pipelines are longer than ten (10) kilometers, so datasets with more than ten thousand points are no exception. For this process, company has decided that a digitizing resolution of one point for every twenty-five (25) meters is sufficient, except when horizontal bends occur in the pipeline route. Off course more station points get added to the PODS database when features are aligned on the centerline.

Old pipelines

Centerlines of old pipelines are only available in 2D. Getting the reliable 3D positions for these pipelines is quite problematic. Also for these centerlines, company has decided that a digitizing resolution of one point for every twenty-five (25) meters is sufficient, except when horizontal bends occur in the pipeline route. Most of the time, the old centerlines do not contain enough control points. This does not matter much, because only the KP-measures of these centerlines will have to be preserved. The horizontal positions will be taken from recently established as-found positions of the pipeline, including burial depth – relative vertical position. These values are taken from the full survey program Sub bottom profiler SEG-Y data, after it is interpreted. Next the as-found positions are overlaid with bathymetry data to establish the absolute vertical position – reduced to LAT. Then these points get connected to form a line and a densify operation will ensure the sufficient digitizing resolution. The vertical position value of the newly added vertices get interpolated. Finally the old 2D centerline KP-measures will be applied to the new 3D centerline by means of linear referencing tools.

V. Changing geometric properties of a pipeline and KP-values

The geometric properties of the pipeline change when a concept pipeline routing is designed in detail, when the designed pipeline is installed (as-built), when the installed pipeline is trenched (as-trenched), when the trenched pipeline is experiencing instability throughout the production stage caused by environmental conditions (storms, currents and other geomorphologic and hydrographic forces), but also when the data of an old pipeline gets updated with new, more accurate positioning data. How to deal with the different versions of the pipeline and still be able to relate to the same part of the object?

Linear referencing

A system to relate events along the route of the pipeline with the pipeline itself is linear referencing. In this system, the geometric properties of the pipeline are expressed by a centerline. This centerline consists of x,y and z coordinates, with linear referencing values expressed by the KP-value (kilometric point) and offsets measuring the length along the pipeline route. The same system can be used to relate between the different versions of the pipeline by using the coordinates, including the KP-value, of the older version as calibration points, since with the changes of the geometric properties of the pipeline, the KP-values of the centerline need to be calibrated. To illustrate this, a problem from practice is presented here (see Figure 40: calibrating KP-values).

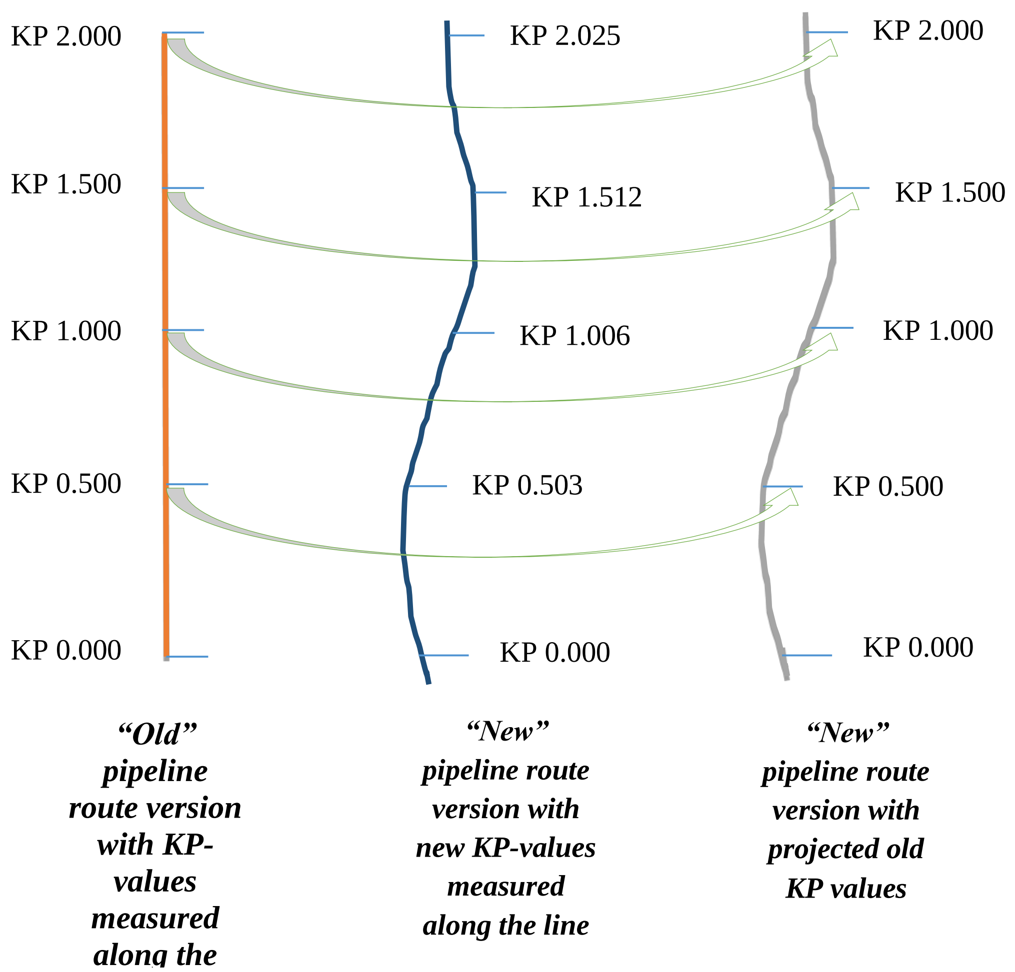


Figure 40: calibrating KP-values

The positioning systems used during installation of old pipelines (1970's) were quite inaccurate compared with current systems. An old coordinate listing of the old pipelines was still being maintained to describe the geometry of the pipeline, for sake of historic references. However, the current survey systems detect the pipeline to be somewhere quite different. Simply updating the centerline with the newly acquired data and generating new KP-values is not an option: if measured along the line, an accumulative error in KP-value occurs. Relating historic data to the new centerline gives mismatches.

Projection of KP-values from the old centerline is required. Company uses the linear referencing tools in ESRI ArcMap to generate correct KP-values on the new line.

VI. Geodetic parameters

COORDINATE SYSTEM IN USE BY GDF SUEZ E&P NEDERLAND B.V.

Local datum geodetic parameters

Datum	European Datum 1950 (ED 50)
Spheroid	International 1924
Semi-Major Axis	a = 6378388.000 m
Semi-Minor Axis	b = 6356911.946 m
First Eccentricity Squared	e2 = 0.006722670
Inverse Flattening	1/f = 297.000

Projection parameters

Projection Universal	Transverse Mercator (UTM)
Zone	31 North
Central Meridian	3° East
Origin Latitude	0° North
False Easting	500000 m
False Northing	0 m
Scale Factor on CM	0.9996 Units metres

DGPS geodetic parameters

Datum	WGS 84
Spheroid	World Geodetic System 1984 (WGS 84)
Semi-Major Axis	a = 6378137.000 m
Semi-Minor Axis	b = 6356752.314 m
First Eccentricity Squared	e2 = 0.006694379
Inverse Flattening	1/f = 298.2572236

UKOOA defined datum transformation parameters from WGS 84 to ED 50

Shift parameters		**Rotation and Scale parameters**	
dX	+89.5 m	rX	+0.000 arcsec
dY	+93.8 m	rY	+0.000 arcsec
dZ	+123.1 m	rZ	+0.156 arcsec
		Scale factor -1.2 ppm	

VII. Overview of company pipeline assets

The full list of pipeline assets of the company is given below. IMPS Code is the Integrity Management Pipeline Systems' code for the pipeline. The Pipeline Code FUGRO is the code that has been used by one of the survey companies. Many of the historic pipeline data is expressed in this code. Pipeline Section Identifier (Short description) is a name of the pipeline, consisting of start and end point of the line (usually platforms)
.

IMPS Code	Pipeline Code FUGRO	Pipeline Section Identifier (Short Description)
GP-001	G03	L10-B to L10-AP
GP-002	G13A	K12-A to L10-AP
GP-003	G32A	K12-G to L10-AP
GP-004	G43A	K12-K to K12-BP
GP-005	G39A	G16a-A to G17d-AP
GP-006	G38	K02b-A to ST KP 61.88
GP-007	G40A	G14-A to G17d-AP
GP-008	G44A	G14-B to G17d-AP
GP-009	G55	E17a-A to ST KP 35.73
GP-010	G01	L10-B to L10-AD
GP-011	G04A	L10-C to L10-AP
GP-012	G05A	L10-D to L10-AP
GP-013	G06A	L10-E to L10-AP
GP-014	G07	L10-E to ST KP 3.86
GP-015	G08A	L10-F to L10-AP
GP-016	G09A	L10-G to ST KP 6.44
GP-017	G11A	L10-L to L10-AP
GP-018	G24A	L14-S1 to L11-A
GP-019	G24B	L14-S1 to L11-A
GP-020	G15A	K12-D to K12-C
GP-021	G17A	K12-C to ST KP 8.6
GP-022	G31A	L10-M to L10-AP
GP-023	G33	K09ab-B to ST KP 106.76
GP-024	G56A	G16a-B to G17d-AP
GP-025	G25	L14-S1 to L11-A
GP-026	G27A	L10-S2 to L10-AP
GP-027	G26A	K11-B to K12-C
GP-028	G29A	L10-S4 to L10-AP
GP-029	G34	K12-S2 to K12-C
GP-030	G36	K12-S3 to K12-BP
GP-031	G41	G17a-S1 to G17d-AP
GP-032	G35	K12-S2 to K12-C
GP-033	G26B	K11-B to K12-C
GP-034	G28	L10-S2 to L10-AP
GP-035	G30	L10-S4 to L10-AP
GP-036	G42	G17a-S1 to G17d-AP
GP-037	G02	L10-B to L10-AD

IMPS Code	Pipeline Code FUGRO	Pipeline Section Identifier (Short Description)
GP-038	G04B	L10-C to L10-AP
GP-039	G05B	L10-D to L10-AP
GP-040	G06B	L10-E to L10-AP
GP-041	G08B	L10-F to L10-AP
GP-042	G09B	L10-G to ST KP 6.44 (ST KP 7.13)
GP-043	G11B	L10-L to L10-AP
GP-044	G13B	K12-A to L10-AP
GP-045	G15B	K12-D to K12-C (ST KP 8.6)
GP-046	G17B	K12-C to ST KP 8.6
GP-047	G27B	L10-S2 to L10-AP
GP-048	G29B	L10-S4 to L10-AP
GP-049	G31B	L10-M to L10-AP
GP-050	G32B	K12-G to L10-AP
GP-051	G39B	G16a-A to G17d-AP
GP-052	G40B	G14-A to G17d-AP
GP-053	G43B	K12-K to K12-BP
GP-054	G44B	G14-B to G17d-AP
GP-055	G56B	G16a-B to G17d-AP
GP-056	G37	K12-S3 to K12-BP
GP-057	G10A	L10-K to ST KP 6.52
GP-058	G10B	L10-K to ST KP 6.52 (ST KP 7.13)
GP-059	G12A	L10-S3 to L10-AP
GP-060	G12B	L10-S3 to L10-AP
GP-061	G14	K12-A to K12-CC
GP-062	G16	K12-E to K12-C
GP-063	G18	ST KP 12.4 to K12-E
GP-064	G19	K12-E to L10-S3
GP-065	G20	K12-S1 to K12-BP
GP-066	G21	K12-S1 to K12-BP
GP-067	G22	K12-S1 to K12-BP
GP-068	G23	K12-S1 to K12-BP
GP-069	G60A	D18a-A to D15-FA
GP-070	G60B	D18a-A to D15-FA
GP-071	G59A	L05a-D to L05-FA
GP-072	G59B	L05a-D to L05-FA
GP-073	G57	Q13a-A to P15-C
GP-074	G58	Scheveningen to Q13a-A
NP-001	N56	L10-AR to NGT Plant
NP-002	N58	D15-FA to L10-AR
NP-003	N50	K12-BP to L10-AR
NP-004	N59	G17d-A to ST KP 118.9
NP-005	N51	K09c-A to L10-AR
NP-006	N52	K06-C to K09c-A
NP-007	N53 & N54	L08-G to ST KP 20.4

IMPS Code	Pipeline Code FUGRO	Pipeline Section Identifier (Short Description)
NP-009	N55	L11-A to ST KP 20.4
NP-010	N60	K09ab-A to ST KP 17.05
NP-011	#N/A	NGT Plant to LS Roodeschool
TP-001	NP024	L02-FA to Callantsoog KP 148.388
TP-002	#N/A	Callantsoog KP 148.388 to NOGAT Plant
TP-003	NP025	F03-FB to L02-FA
TP-004	NP026	L05-FA to ST KP 19.671
TP-005	NP027	L15-FA to ST KP 82.753
TP-006	NP028	F03-FB to F03-FB OLT
TP-007	NP030	F15-FA to ST KP 71.498
TP-008	NU029	F03-FB to F03-FB OLT
XP-001	T01	L7-P to L10-AR
XP-002	W25	P6-A to L10-AR
XP-003	W45	D12-A to D15-FA
XP-004	W46	D12-A to D15-FA
XP-005	G46	Minke to D15-FA
XP-006	G45	Minke to D15-FA
XP-007	?	Wingate to D15-FA
XP-008	?	Wingate to D15-FA
XP-009	A01	L6d-S1 to G17d-AP
XP-010	A02	L6d-S1 to G17d-AP
XP-011	NP036	L09-FF-1 to STKP 58.232
XP-012	S009	AWG-1 to ST KP 118.9
XP-013	W20	L8-P4 to ST KP 20.4
XP-014	W48	TYRA to F03-FB-1
XP-015	M01	TYRA to F03-FB
XP-016	M02	F03-FB to F03-FB SSVS
XP-017	W43	A6-A to F03-FB
XP-018	W44	A6-A to F03-FB
XP-019	N61	L11-B to ST KP 14.4

VIII. Overview of company platform assets

A start has been made to make one master list with names for all company's platform assets. Throughout the company, many different names are used for the platforms. It is hoped that with the development of the IMPS system, the names of the platforms will get uniformly used. CODE is a simple code, including the prefix 'SIT' for site, following ascending triple digit numbers. Name is the proposed name for the site.

CODE	Name
SIT001	A6-A
SIT002	AWG-1
SIT003	Callantsoog KP 148.388
SIT004	D12-A
SIT005	D15-FA
SIT006	D18a-A
SIT007	E17a-A
SIT008	F03-FB
SIT009	F03-FB OLT
SIT010	F03-FB SSVS
SIT011	F15-FA
SIT012	F16-A
SIT013	G14-A
SIT014	G14-B
SIT015	G16a-A
SIT016	G16a-B
SIT017	G17a-S1
SIT018	G17d-A
SIT019	G17d-AP
SIT020	K02b-A
SIT021	K06-C
SIT022	K09ab-A
SIT023	K09ab-B
SIT024	K09c-A
SIT025	K11-B
SIT026	K12-A
SIT027	K12-BP
SIT028	K12-C
SIT029	K12-CC
SIT030	K12-D
SIT031	K12-E
SIT032	K12-G
SIT033	K12-K
SIT034	K12-S1
SIT035	K12-S2
SIT036	K12-S3
SIT037	L02-FA
SIT038	L05a-D
SIT039	L05-FA

CODE	Name
SIT040	L06d-S1
SIT041	L08-G
SIT042	L09-FF-1
SIT043	L10-AD
SIT044	L10-AP
SIT045	L10-AR
SIT046	L10-B
SIT047	L10-C
SIT048	L10-D
SIT049	L10-E
SIT050	L10-F
SIT051	L10-G
SIT052	L10-K
SIT053	L10-L
SIT054	L10-M
SIT055	L10-S2
SIT056	L10-S3
SIT057	L10-S4
SIT058	L11-A
SIT059	L11-B
SIT060	L14-S1
SIT061	L15-FA
SIT062	L7-P
SIT063	L8-P4
SIT064	LS Roodeschool
SIT065	Minke
SIT066	NGT Plant
SIT067	NOGAT Plant
SIT068	P15-C
SIT069	P6-A
SIT070	Q13a-A
SIT071	Scheveningen
SIT072	ST KP 106.76
SIT073	ST KP 118.9
SIT074	ST KP 12.4
SIT075	ST KP 14.4
SIT076	ST KP 17.05
SIT077	ST KP 19.671
SIT078	ST KP 20.4
SIT079	ST KP 3.86
SIT080	ST KP 35.73
SIT081	ST KP 6.44
SIT082	ST KP 6.52
SIT083	ST KP 61.88
SIT084	ST KP 7.13

CODE	Name
SIT085	ST KP 71.498
SIT086	ST KP 8.6
SIT087	ST KP 82.753
SIT088	ST KP 58.232
SIT089	TYRA
SIT090	Wingate