Integration of Simulation Capabilities in Domain-Specific Modeling Languages for Pipeline System Analysis

Musa, Muhammed
Department of Computer Science,
Faculty of Sciences,
Niger Delta University,
Wilberforce Island, Bayelsa State Nigeria
muhammedmusa630@gmail.com
ORCID: 0000-0001-8670-4022

Aluye-Benibo, Data
Department of Community Health Nursing
Faculty of Nursing Sciences
Niger Delta University
Wilberforce Island, Bayelsa State Nigeria
aluyedata@gmail.com

Musa, Aminu
Department of Geography,
Faculty of Social Sciences,
Kogi State University, Anyigba, Nigeria
aminumusa669@gmail.com

Ziakegha lucky Tonbrapagha
Department of Computer Science,
Faculty of Sciences,
Niger Delta University,
Wilberforce Island, Bayelsa State Nigeria
tonbraziakegha@gmail.com

Sanu Momoidu Kabiru
Department of Computer Science,
Faculty of Sciences,
Niger Delta University,
Wilberforce Island, Bayelsa State Nigeria
kabiruproject@gmail.com

Amaogbo, ANDERLINE
Department of Computer Science,
Faculty of Sciences,
Niger Delta University,
Wilberforce Island, Bayelsa State Nigeria
anderlineamaogbo@yahoo.com

SEGU Tonye George
Department of Computer Science,
Faculty of Sciences,
Niger Delta University,
Wilberforce Island, Bayelsa State Nigeria
tonye2050@gmail.com

Abstract

Formal specifications are essential for ensuring the accuracy, reliability, and efficiency of complex systems, such as those found in the oil and gas industry. This paper examines the significance of formal specifications in the design and analysis of oil and gas sector-specific systems. In this industry, where safety and precision are critical, formal specifications offer a systematic approach to defining system requirements, behaviors, and constraints. The integration of simulation capabilities within domain-specific modeling languages

enhances this approach by enabling dynamic analysis and performance evaluation of pipeline systems. By employing formal methods like mathematical logic and modeling languages, engineers can accurately represent the intricate details involved in system design, while simulation provides valuable insights into system behavior under various operational conditions. To illustrate the value of requirements in the oil and gas industry, this paper introduces a modeling language based on domain-specific modeling methodology, augmented with simulation features. Predicate calculus is utilized to ensure precision, clarity, and unambiguous communication among stakeholders. Furthermore, formal verification and validation techniques using MATLAB were applied to identify potential issues and ensure adherence to industry standards and regulatory guidelines. The results demonstrated an accurate and dynamic representation of the pipeline system, offering enhanced insights for refining design workflows and optimizing system performance.

Keywords: Oil and gas industry, Design and analysis systems, Formal methods, Verification and validation, Requirements, Efficiency.

1. Introduction

The oil and gas industry stands as a brace of the global economy, providing the energy resources that power essential infrastructure and drive numerous industrial processes. The design and analysis of systems within this sector are particularly critical, as even minor errors or oversights can have far-reaching consequences, impacting not only operational efficiency but also posing significant risks to the environment and human safety. In this high-stakes environment, formal specifications have emerged as a crucial tool for ensuring the reliability, safety, and precision of oil and gas design and analysis systems. Formal specifications, in essence, provide a means of precisely defining the behavior and properties of complex systems through mathematical and logical representations. Unlike informal documentation or ad-hoc design processes, formal specifications offer a rigorous and structured approach to system development, enabling thorough analysis, verification, and validation of system behaviors. With the increasing complexity of oil and gas systems, the need for formal specifications has become more pronounced, as they offer a systematic means of addressing the intricate interdependencies and requirements essential in these systems. The application of formal specifications within the context of the oil and gas industry is multifaceted, encompassing various aspects of system design, analysis, and validation. By employing formal methods, the industry can enhance its capability to understand, predict, and mitigate potential risks, thereby bolstering safety and minimizing the likelihood of costly errors. Furthermore, formal specifications play a crucial role in addressing the industry's firm regulatory requirements, as well as its evolving technological landscape, where precision, efficiency, and integration are paramount. This paper aims to provide a comprehensive examination of the role of formal specifications in oil and gas design and analysis systems, shedding light on their significance and real-world applications. Traditional modeling languages, such as UML, have not significantly boosted productivity because the core models are at the same level of abstraction as the programming languages that support them. The user still needs to code by hand to confirm to the objects constraint language (OCL) and the meta-object facility (MOF) diagram definition standards (Nguyen, 2022). Conventional computer aided design and modeling systems has never helped either. Manual editing is still required to complete a modeling task; and it could take a whole day worth of code to define behaviours of solids. All of these efforts are attempts to keep the same information in both code and models, which is always a challenging approach. Why was the transition from Assembler to BASIC such a significant leap, and how can we replicate that progress today? The reason was because abstractions about the Assembler instances were raised and hidden under the BASIC code. We can as well achieve the same productivity level in software development by adopting Domain-specific modeling for productivity. Domain-Specific Modeling elevates the level of abstraction and conceals the underlying programming languages, much like how modern programming languages abstract away assembly language. In a domain-specific model, the symbols represent elements within the specific domain or context where the application will operate.

2. Related Work

Domain-Specific Languages, rightly put by, are essentially Domain-Specific Modelling Languages (DSMLs). One key observation is that many software development challenges can be more effectively addressed by creating a specialized language. Jan Goyvaerts, in his contributions, provided an example of a specialized .Net class, the System regular expression language, which spares developers from the tedious and error-prone task of writing complex programs by automatically assigning the correct values to the relevant variables. Emphasizing on the ease of problem solving in computing systems, Steve et al. exemplified the applicability of Domain Specific Languages in managing the complexity of modern distributed systems on the .NET platform. Usually in the form of either textual or graphical, DSLs are ways of providing solutions to variable domain specific problems that may arise.

2.1 Textual /Graphical DSLs

Textual DSLs as the name implies do provide interfaces for input. The functioning of textual DSLs relies on defining the grammar of input parameters using formal notation, which is then parsed or interpreted for processing. In contrast, graphical DSLs go beyond just diagrams, but can enable the visualization of the required solutions as diagrams. In that way not much external grammar parsing is required for its implementation. Building on the essential structural framework required for a textual DSL to execute its core functions, this research is aligning with this design paradigm in the development of the language. The creation of fragments of grammar for specifying the different components involved in building the pipeline within the language.

```
Define PipeBuild Shape
build_pipe {
length=0.2, (decimal/double)
thickness=20, (float)
diameter_inner=8, (float)
```

diameter_outer=10, (float)
colour=brown, (string)
pipe_type ="steel, fiberglass, etc", (string) point_x = 124, (int)
point_y= 124, (int)
point_z= 124, (int)
slope = 180, (int)
weight = 2000.500 (float)
*******direction =
}pipe_join.method.thispipe.p(0,1)

In order to process this grammar as is the case with textual DSLs, it must be described in a formal notation such as Backus Naur Form (BNF) as shown below
BuildPipe Eq Build
OutlineDimension Eq Dimension
Builder*
End Id
Shape ::= Cylinder| ConeFrustum | Ellipse
Eq ::= "="
Builder ::= Builder Id
Position Eq Position
End Id
Position ::= Center|
InnerDiameter |OuterDiameter |Lenght |Slope
Definitions ::= Definition*
Definition ::= Define Id Shape
Width Eq Number
Thickness Eq Number

2.2 XMF and XMF-Mosaic

XMF is an advanced, high-level object-oriented language built on a compact virtual machine written in Java. It is suited particularly for developing Domain Specific Languages. The successful development of a DSL with XMF is achieved especially for the fact that it has features that can be interfaced to Java including the Eclipse Modelling Framework (EMF) and connects to input/output data streams. Another notable feature of XMF is its support for first-class grammars, which can be used to define new language features that are instantly integrated into the core language. Historically came into existence under the Eclipse Public License as open-source software.
The mode of operation often begins by reading commands, at the top level of XMF is a command interpreter that reads command in a loop fashion. These commands are then subject to evaluation and subsequent results printed in a console. In essence, the valid XMF syntax, represented by XOCL, along with language extensions defined using XBNF, are parsed and interpreted by the system.
The understanding process builds the binding of the objects because XOCL standard expressions represents a combination of Eclipse Frameworks and objects Constraint Language (OCL) to define the DSL. The definition of the DSL usually is in the form of a runtime model for update annotations, and as extensions of the OMG standard with static and dynamic semantics.
XMF-Mosaic is essentially written in XMF, it only provides a wider architecture for modelling that is based on class diagrams. Since it is written in XMF, many features of the XMF-Mosaic modeling environment can be redefined and expanded by loading new XMF code, which can subsequently be executed using the XMF language.

3. Method and Materials

3.1 Methods

Model-Driven Engineering (MDE) is a set of methodologies that support the creation of domain-specific languages. Wang and Liu (2021) identify two primary approaches to MDE: Model-Driven Architecture (MDA) and Domain-Specific Modeling (DSM). MDA, a component of the Object Management Group (OMG) standards, supports a model-driven approach through tools like the Unified Modeling Language (UML), XML Metadata Interchange (XMI), and the Meta-Object Facility (MOF) (Chen & Zhang, 2023). A key characteristic of the MOF/UML package is its incomplete syntax mappings, which complicate model interchange. Due to the complexity of the language specification, it often requires the diagram definition standard to address these shortcomings (Patel, V., 2020).
The Domain-Specific Modeling approach (Nguyen & Tran, 2022) is characterized by the use of a Domain-Specific Modeling Language (DSML), which generally targets requirements within particular domains, such as oil and gas pipeline systems. Models are developed using a language that defines the relationships between concepts within the domain and clearly specifies the key semantics and constraints associated with these concepts (Patel et al., 2020).

3.1.2 Language Metamodel

MDE with the DSML approach is declarative, primarily concentrating on specifying what the program is meant to accomplish while abstracting the complexities of how to solve the problem through specific sequences of actions (Tran, T., 2022). Policies are defined at a higher level of abstraction using models, separate from the mechanisms that enforce these policies.
DSMLs are defined using metamodels, which help bridge the semantic gap between the intended design and its representation. This enables users of these languages to bypass the complexities of how policies are translated into the underlying mechanisms that implement them (Johnson, M., 2024).

3.1.3 The Domain Model

Domain Model represents real world concepts and vocabulary of the problem domain. A software engineering research activity like this work that relates to modeling language development for pipeline systems specific domain, the need for a domain model arises from its role as the precise conceptual framework that illustrates the semantics and workflow of the language (Smith & Johnson, 2024).
Domain classes and relationships are the fundamental elements that define a domain model. In our case, this refers to the model that represents oil and gas pipeline concepts in relation to the core language definitions (Tran, 2022).
By focusing the model at the core of development and omitting details that are not relevant to the application domain it represents, the concepts associated with the domain's technical content are defined (Martinez & Garcia, 2021; Brown & Wilson, 2023).

Pipeline systems are akin to arteries and veins in the human body; they are essential and integral to modern civilization, much like blood vessels are to the body's functioning. In a modern city, pipelines transport water from supply sources to distribution points. Likewise, they carry crude oil or gas from wells to storage tanks or refineries for processing (Wang, 2024).

3.1.4 Pipeline Standards and Operations

The design, construction, operation, and maintenance of pipeline systems demand a thorough understanding of pipeline fundamentals, materials, both general and specific design considerations, fabrication and installation procedures, as well as testing, inspection, and examination requirements. Furthermore, adherence to local, state, and federal regulations is crucial (Li, X., 2024).

Pipeline systems are made up of pipes, flanges, fittings, bolts, gaskets, valves, and the pressure-containing sections of other piping components. Additionally, they include pipe hangers, supports, and other components designed to prevent over-pressurization and excessive stress on the pressure-bearing parts (Kim, D., 2023).

It is evident that the pipe is the central element in pipeline systems. When pipe sections are joined with fittings, valves, and other mechanical components, and properly supported by hangers and supports, they create a complete pipeline (Gupta, A., 2021). A pipe is a cylindrical tube with a round cross-section, conforming to the dimensional standards specified in the American Society of Mechanical Engineers (ASME) B36.10M for Welded and Seamless Wrought Steel Pipe and ASME B36.19M for Stainless Steel Pipe.

The inside diameter of a pipe is determined by its wall thickness, as specified by the schedule number, referencing ASME B36.10M or ASME B36.19M. Alternatively, pipe size can be indicated using the nominal diameter (Johnson, L., 2024). Nominal Diameter (DN) is a dimensionless designation for pipe size in the metric system, developed by the International Standards Organization (ISO). It represents a standard pipe size when followed by a specific size number. For example, for pipe sizes larger than NPS 80, the corresponding DN size can be calculated by multiplying the NPS size number by 25, omitting the millimeter symbol (Pipeline 101, 2022).

3.1.5 Generic Pipeline Design Considerations

Engineers tasked with preparing design documents must regularly review current codes and standards to ensure compliance and to benefit from ongoing industry changes, especially as computerized drafting, text preparation, and record-keeping continue to advance, it is often advantageous to develop a comprehensive set of documents that outline the system design criteria before beginning the detailed design phase. These criteria may be incorporated into the broader project design documents or may exist as a separate document dedicated specifically to the piping design (Smith, E., 2024).

In either case, the design criteria should reinforce the design requirements specified in the contract and outline the applicable codes and standards, environmental conditions, design parameters, and other essential factors that will govern the work. These criteria may be updated as the design progresses to reflect any changes in the foundational design (Anvil International, 2021).

3.1.6 Analysis of the Existing Language System

Formal Specifications for Oil and Gas Design and Analysis Systems can be approached using Predicate Calculus to ensure rigorous and precise definitions. Predicate Calculus is a formal system for representing and reasoning about relationships between objects, which is well-suited for specifying complex systems like Oil and Gas Design and Analysis Systems. The current design relies on informal domain descriptions represented through UML (Unified Modeling Language). Specifically, the methodology involves two main processes. The first process focuses on designing the domain-specific language (DSL) and providing the necessary tool support. The second process involves verification, which is applied when using the output from the design phase. This verification process is based on the tools developed in the first phase. It includes the domain engineer categorizing all relevant concepts, attributes, and relationships within the domain into an informal DSL, which is visualized through UML class diagrams

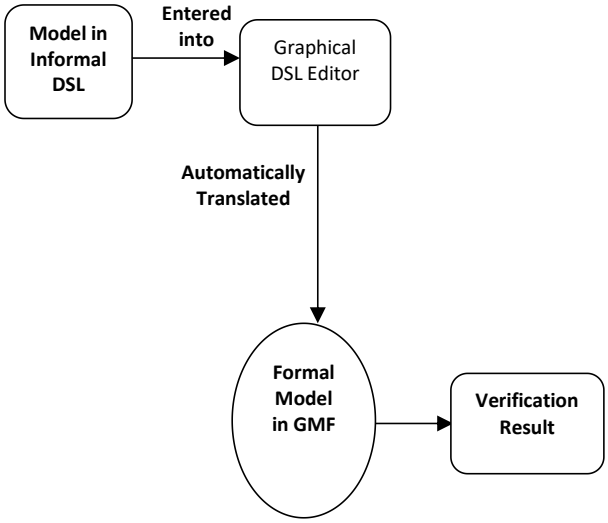

Figure 1: Verification Process Based on Design (Garcia & Wang, 2021)

3.2 Materials

3.2.1 Feature Constraints

Since feature models are semantically connected to propositional logic, the feature diagram is translated into propositional logic representations to support analysis, transformation, and interactive configurations. Interactive configuration involves assigning features based on the current state of the system and updating the information as new selections are made. The diagram's top tree includes a root feature, Pipeline (r), along with mandatory features such as Components (c), Fittings (f), Joint (j), and Support (s), as well as an optional feature, Pipe Bed (b). It also features alternative options, NPS (d1) and DN (d2), and an exclusive-or group that includes the grouped features, Meter (m) and Gauge (g). These define the standard reference attributes and relationships for the features within the product family. The product family specifies the pipeline components c, f, j, b, and s, along with an associated tree grammar. According to the

grammar, b is an optional feature, meaning its child features, such as L, LR, and LN, may or may not be part of the design system configuration. The other parent features, c, f, j, and s, are compound features that include mandatory elements D, P, and T. This indicates that D, P, and T must be included in the configuration only if c, f, j, and s are also present.

Parent Features

Pipeline (root) $\Rightarrow r$
Components $\Rightarrow c$
Fittings $\Rightarrow f$
Joint $\Rightarrow j$
Pipe Bed $\Rightarrow b$
Support $\Rightarrow s$

Child /Sub features

Dimension $\Rightarrow D$
Point $\Rightarrow P$
Type $\Rightarrow T$
Law $\Rightarrow L$
Route $\Rightarrow LR$
Location $\Rightarrow LN$

$r: cfj[b]s;$
$c: D \mid P \mid T;$
$f: D \mid P \mid T;$
$j: D \mid P \mid T;$
$b: L \mid LR \mid LN$
$s: D \mid P \mid T$

The feature variability relationships and constraints for the interactive configurations and transformation are described below.

Rule 1. *elbowFitting* $\rightarrow$ *jointType*:
If pipeline will transmit fluid then *elbowFitting requires joint*
Constraint 1. $r \rightarrow c \wedge f \wedge j \wedge b \wedge s$

Rule 2. *metreComponent mutex – with pipeSupport*:
Pipe supports does not require flow meters in the entire pipelir
Constraint 2. $c \rightarrow t \wedge (\exists t \wedge s)$

Rule 3.
If pipe cross sections are dimensioned then *pipeComponent requires dimens*
pipeComponent $\rightarrow$ *dimensionUnits*:
Constraint 3. $c \rightarrow d \wedge (d_1\ x - or\ d_2)$

Rule 4. *pipeOrigin* $\rightarrow$ *fittingTypes*:
If the pipe origin is to be connected to source then *pipeOrigin requires fitti*
Constraint 4. $c \wedge p \rightarrow f \wedge t$

Rule 5. *jointType* $\rightarrow$ *valveComponent*:
Globally fitting are used along side with valves in the pipeline
Constraint 5. $j \wedge t \rightarrow c \wedge t \Rightarrow f \wedge d \wedge p \wedge t$

Rule 6. *pipeOriginTerminal* $\rightarrow$ *pipeSupport*:
Globally, pipe supports are positioned strategically to set the direction
Constraint 6. $c \wedge t_1 \rightarrow c \wedge t_2 \wedge (c \wedge f \wedge j \wedge b \rightarrow s)$

3.2.2 Formal Definitions

The formal definitions include the syntax and semantics of the feature model, as well as the configurations of the features. The syntax of the feature model represents the organizational structure of features within the pipeline domain. The semantics define the configuration constraints, including feature attributes, the cardinality of feature relationships, interdependencies, Changes in system states caused by feature compositions, along with the domain-specific operational rules for the pipeline.

The essence is that, since the semantics of the composed system is the functional quality aspect, the feature model syntax defines the semantics of the composed system. It therefore means that as long as the features are composed in a proper hierarchy, The composed system operates correctly, provided that the features are implemented properly. For instance, when constructing a pipeline design modeling system by combining feature components and fittings, the specification of the fittings' positions represents the semantics of the integrated system.

3.2.3 Syntax Definition

A syntax definition for the pipeline design modelling language feature model is presented in this section.

Definition 1

The feature diagram, known as the Pipeline Feature Diagram (PFD), represents the core features of the pipeline design modeling language. It is a labeled graph with nodes \(n \in X \).

Dfn: $n \in X \Rightarrow X = \{n \mid n$ *is all features of Pipeline Domain*$\}$
$= X(n)\ \forall\ n$ *in the domain*
$\Rightarrow \forall\ n\ X(n) =$ *TRUE for all features under consideration*
$= \forall\ n\ X(n) = X(n_1) \wedge X(n_2) \wedge X(n_3) \wedge \ldots\ldots \wedge X(n_e)$

Therefore, given nodes n ∈X: a node type could either be:

(a) EXCLUSIVE OR NODE: An x-or-node, denoted as \(x \in D \), represents features that are realized by selecting exactly one child sub-feature. These nodes are depicted with an arc connecting their outgoing links, as illustrated in the "Dimensions" section.

$\exists\ x \in D\ \forall\ x$ *in the feature Dimension*

$\Rightarrow \exists\ xD(x) =$ *TRUE for all ATTRIBUTES under the feature Dimension*

$\Rightarrow \exists\ xD(x) = \{x \mid x = D(x_1) \vee D(x_2) \vee D(x_3) \vee \ldots\ldots \vee D(x_e)\}$

(b) OR NODE: or-node x ∈ T, Denoting features that are realizable by selecting one or more child sub feature, as seen in Meter and Gauge sub features under Components Type (T)

$\exists\ x \in T\ \forall\ x$ *in the sub feature Component Type*

$\Rightarrow \exists\ xT(x) =$ *TRUE for all ATTRIBUTES under the sub feature Component Type*

$\Rightarrow \exists\ xT(x) = \{x \mid x = (T(x_1) \vee D(x_2)) \wedge (T(x_3) \vee D(x_4)) \vee (T(x_1) \wedge T(x_2)) \vee (T(x_3) \wedge T(x_4))\}$

(c) AND NODE: An and-node, denoted as \(x \in J \), represents features that are realized by selecting all of their child sub-features, such as in the case of a Joint.

$\exists\ x \in J\ \forall\ x$ *in the feature Joint*

$\Rightarrow \exists\ xJ(x) =$ *TRUE for all ATTRIBUTES under the feature Joint*

$\Rightarrow \exists\ xJ(x) = \{x \mid x = J(x_1) \wedge J(x_2) \wedge J(x_3) \wedge \ldots\ldots \wedge J(x_e)\}$

(d) (d) And optionally: \(x \in B \), which is optional for selection and is represented by a small hollow circle, as seen in Pipe Bed.

(e) (e) *A node, typically an and-node type, represents the unique concept in the feature diagram, or the root \(r \in X \), and is placed at the top of the tree. An example of this is the Pipeline \(r \in P \).*

(f) (f) *Leaf nodes, \(f \in X \), are features depicted at the bottom of the diagram.*

Definition2

The feature diagram, known as the Pipeline Feature Diagram (PFD), represents the core features of the pipeline design modeling language. It is a labeled graph with edges \(\rightarrow N \times N \).

$$Dfn: x \in N \Rightarrow N = \{x \mid x \text{ is all Directed Edges of Feature Diagram} = N(x) \forall x \text{ in the domain} \Rightarrow \forall x N(x) = TRUE \text{ for all Edges under consideratio} = \exists x N(x) \{x \mid x = N(x_1) \vee N(x_2) \vee \ldots \vee N(x_e)$$

The edges are directed, as indicated by the arrows. Starting from an arbitrary node (N), traverse all possible edges (x) by following the direction of the arrows, ensuring that you never return to node N.

Therefore FD edges $\rightarrow N \times N$ are labelled mandatory (m) from root concept (r),

$$\text{is a } 5-\text{tuple; such that } FD = (N, P, r, \lambda, DE,)$$

where:

$N = \{n_1, n_2, \ldots, n_e\}$ *is its set of nodes;*

$P \in N$ *is its set of primitive nodes;*

$r \in N$ *is the root of the FD, also called the concept;*

$\lambda: N \rightarrow NT$ *labels each node from the node type (NT);*

$DE \in N \times N$ *is the set of decomposition edges;*

(a) *Only r has no parent:* $\forall n \in N.(\exists n' \in N.n' \rightarrow n) \Leftrightarrow n = r.$

(b) *DE is a tree:* $\exists n_1, n_2, n_3 \in N.n_1 \rightarrow n_2 \wedge n_3 \rightarrow n_2 \wedge n_1 \neq n_3$

(c) *DE hierarchy is acyclic:* $\exists n_1, \ldots, n_e \in N.n_1 \rightarrow \ldots \rightarrow n_e \rightarrow n_1.$

i.e. $\neg(n_1 \rightarrow \ldots \rightarrow n_e \rightarrow n_1)$

(d) *Nodes are labelled with the appropriate arity:*

$$\forall n \in N.\lambda(n) = p_e \rightarrow n'$$

Definition3

(a) *The feature diagram, referred to as the Pipeline Feature Diagram (PFD), illustrates the fundamental features of the pipeline design modeling language. It is a labeled graph with nodes \(n \in X \), where edges \(\rightarrow N \times N \) are labeled as mandatory (m) starting from the root concept (r). Specifically, \(n \in X \) represents a set of constraints in the following forms:*

n_1 *mutex* n_2,

or

n_1 *requires* n_2.

3.2.4 Semantics Definition

The semantic units are precisely defined to represent the concurrency and communication abstractions of the features within the pipeline product family. The domain model includes all these units and their interrelationships, reflecting the problem domain, specifically outlining what the existing systems are required to accomplish in the pipeline design context. It complements our architecture (i.e., the solution space), where the system is designed to satisfy the requirements of the operating environment. The goal is to provide domain experts with concepts specifically adapted to the unique characteristics of the application domain. The central concept is to integrate formal methods with practical pipeline engineering principles in the creation of a domain-specific modeling language.

The formal semantics are defined by the Pipeline Design Product Line Model (PDPM). In the feature model, a product (P) includes information about a set of leaves. The model (M) of the feature diagram contains the values of products as a subset of primitive nodes, while the constraints (C) establish the rules that govern the specific definitions.

$$A \text{ PDPM is a triple } (P, M, C)$$

Where:

$P = \{p_1, p_2, p_3, \ldots\ldots, p_e \in P\}$ *is the set of leaves* $P = p(F)$

$M = m \in M$ *is the subset of the nodes of the FD:* $M = pN$

$C = \phi \in \Phi$; *are the satisfyable constraints*

Definition 1

The product line with a set of feature leafs (F)

of the pipeline design modelling system FD is a valid model $m \in M$ *iff:*

(a) *The concept is in the model:* $r \in m$

(b) *i. If a xor – node is in the model, exactly one of its sub features is:* $q \in m$

$$\Rightarrow \exists! n.q \rightarrow n \wedge n' \in m$$

ii. If a and – node is in the model, all its subfeatures are: $k \in m$

$$\Rightarrow \forall n.(k \rightarrow n \Rightarrow n' \in m)$$

(c) *i. The model must satisfy the constraint set:* $\forall \phi \in \Phi, m \vDash \phi$

where:

$m \vDash n_1$ *mutex* $n_2 \rightarrow n_1$ *and* $n_2 \notin m$;

$m \vDash n_1$ *requires* $n_2 \rightarrow n_1 n_2 \in m$

ii. Satisfy the textual constraints: $\forall \phi \in \Phi, m \vDash \phi,$

where $m \vDash \phi_1 \rightarrow p_1 \in m \Rightarrow p_2 \in m$ *is true*

iii. Satisfy the graphical constraints: $\forall (n_1 * n_2) \in C, * (n_1 \in m, n_2 \in m)$ *is true*

(d) *Possible in this case are two semantics:*

node – based: $\exists$*mandatory edge* $(e) \in m \Rightarrow n_1, n_2, n_3, \ldots, n_e \in m$

$e_1, e_2, e_3, \ldots e_e \in m \rightarrow * (e \in m, \ldots\ldots, e \in m)$

$edge - based: \forall mandatory\ edge\ (e) \in m \exists!\ e \in m$

Definition2

The product line P with a set of feature leafs (F) of the pipeline design modelling system FD is the set of leaves P = p(F) iff:

(a)The product line is a set of products: $p(P) = p(p(F))$.

(b)The product line is the products of the FDs valid models:

such that $[\![p]\!] = \{m \cap F \setminus m \vDash p\}$

(c)A product k is a set of primitive nodes: $k \in p(P)$.

3.2.5 Model Specification

It is crucial to recognize that PDML models are built using concepts that reflect the goals of stakeholders Within the context of the oil and gas pipeline industry. Therefore, model specification refers to the actual creation of the language specification, specifically the development of the language metamodel. The reason for this is that these models, such as the Pipeline Context Model (PCM), essentially serve as instances of the language metamodel.

4. Result and Discussion

As knowledge advances, the semantic model can be revised to ensure that physical components maintain their intended functionality, as specified by users, while also producing precise design specifications for pipeline assets such as pipes, valves, active equipment (e.g., pumps, compressors), insulation, and supports. Both standard and specialized functions are abstracted and represented, enabling the development of specific design scenarios as adaptations or refinements of the model.

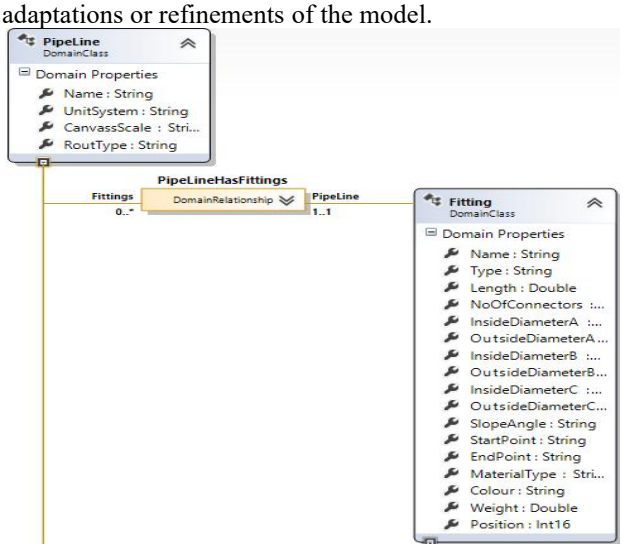

Figure 2: Pipeline Engineering Principles

Figure 2. It illustrates how these elements are interconnected to form the complete pipeline system design operation life cycle. These relationships define the user-centered composition rules of the semantic model, which incorporate the event handler.

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