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Application and Development of Advanced Engineering Geographical Information Systems for Pipeline Design

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Application and Development of Advanced Engineering Geographical Information Systems for Pipeline Design

Herbert Keith Winning

*A thesis submitted in partial fulfilment of the University's
requirements for the Degree of Doctor of Philosophy*

**Coventry University
Buckinghamshire New University**

May 2015

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Abstract

This thesis proposes the use of an Advanced Engineering Geographical Information System (AEGIS) for the improved design of onshore pipelines, from concept to operation. The system is novel in that it is function rather than discipline or software specific.

The thesis statement has been developed, and an aim and set of research objectives identified (along with the success criteria for the evaluation of the system), based on a review of current pipeline design methods.

Drawing on a design science research methodology (DSRM), the thesis proposes the development of the system as an artefact in order to validate the proposed constructs, models, methods and implementations. The thesis discusses the underlying issues of data interoperability, the application of open data standards, and the integration of computer aided design (CAD) and geographical information systems (GIS). These challenges are addressed in the thesis and demonstrated through the implementation of the system.

To support the development of the system, research was undertaken in the fields of pipeline engineering, environmental engineering and engineering design. As part of this research, a number of peer-reviewed journal papers were published, and conference papers presented in Kampala, Houston, London and Split. These papers covered the key fields contained in the thesis including, fluid mechanics, bio-systems engineering, environmental engineering, CAD/GIS integration (CGI), and the application and development of geospatial pipeline data models.

The thesis concludes that the approach is valid, offering significant improvement across all fields compared to the current method of pipeline design. By taking a functional approach to the challenges of the design of pipelines, a system has been developed that addresses the requirements of the pipeline engineer, environmental engineer and engineering designer. The system enables the user to select the software of their choice, thereby reducing the problems associated with data interoperability, retraining and system integration. The sharing of data and outputs from analysis carried out within the system, provides an integrated approach, which can subsequently be used for the integrity management of the pipeline during the operational phase of the project.

The scope for further development of this approach to pipeline design is also discussed. In addition to the inclusion of further engineering and environmental analysis, there is the potential for using the system for the design of subsea pipelines.

Preface

This thesis integrates elements of pipeline engineering, environmental engineering, engineering design, computer aided engineering (CAE), CAD, and GIS to provide an advanced engineering geographical information system for pipelines. While the approach is equally applicable to both onshore and offshore pipelines, the thesis focuses on the application to onshore pipelines.

Chapter 1 introduces the fields within which this research applies. A brief overview of the historical development of onshore pipelines provides temporal context, while the following sections introduce the engineering, environmental and design issues. As the data for the model matures and becomes available at different phases of the project, an overview of the construction and operational phases of the project are also given.

Chapter 2 presents the research question, scope of the research, and sets out the aim, objectives and the success criteria for the thesis. Crucially it introduces and defines the concept of the AEGIS. The key areas for research are identified and the scopes defined for the supplementary literature reviews. These are presented in the respective chapters to which they apply.

Chapter 3 details the research methodology. The overall methodology of the thesis is outlined, together with the selected methodologies for the specific research areas of pipeline engineering, environmental engineering and engineering design (Chapters 4, 5 and 6) respectively. The methods selected for the design and evaluation of the AEGIS (Chapters 7 and 8) are also outlined.

Chapters 4, 5 and 6 cover the research in the fields of pipeline engineering, environmental engineering and engineering design with respective chapters incorporating an introduction, literature review, methodology, analysis and discussion of the topic.

Chapters 7 and 8 detail the development and evaluation of an instantiation of the AEGIS which is termed as the Pipeline Integrated Engineering Environment (PIEE), based on the Software Design Specification (SDS) in Appendix E. In this thesis, the terms AEGIS and PIEE should be read as synonymous.

Finally, Chapter 9 presents the conclusions of the thesis and identifies the aspects of the research that are novel or contribute to the canon of knowledge. Limitations of the current research and areas for further research are also discussed.

Acknowledgements

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I owe an enormous debt of gratitude to my wife Pat, for her unfailing encouragement, support and patience throughout the course of my studies. Balancing the requirements of part-time study with home and work commitments is not always easy, but it is those who support us, rather than the student, that give most and gain least, for as Robert Louis Stevenson said:

Perpetual devotion to what a man calls his business, is only to be sustained by perpetual neglect of many other things. (2009: 4)

I would like to thank my employer, CB&I Limited, for their financial support for attending conferences and my friend Dr Alistair Miller for reading the thesis; his suggestions and comments have helped to improve its clarity, and my thinking.

I would also like to record my gratitude to Dr Mike Hann, Professor Emeritus at Cranfield University, and one of the foremost experts on soil erosion for onshore pipelines. I have been most fortunate to be able to work with him in the field on a number of occasions; nobody could have had a better teacher and I thank him for his tutelage and patience in explaining the fields of soil mechanics and erosion.

All research students owe a tremendous debt to their supervisors and I have certainly been most fortunate in having both Dr Tim Coole and Dr Richard Mather as my supervisors; their guidance, encouragement and support have been instrumental in my getting to this stage. In particular, Dr Tim Coole has been my companion throughout my journey of enlightenment, a journey of almost nine years. He has given me perhaps the most precious gift a master can to his pupil: the conviction that my vision and ability is limited only by my diligence, endeavour, knowledge and desire to learn.

All men dream: but not equally. Those who dream by night in the dusty recesses of their minds wake in the day to find that it was vanity: but the dreamers of the day are dangerous men, for they may act their dreams with open eyes, to make it possible. (Lawrence, 2008: 23)

Finally, I would like to thank all the faculty staff, past and present. They have not only educated and supported me but have also fostered a keen thirst for knowledge that will remain with me always, and for which I am most grateful.

AEGIS, apart from being an acronym for Advanced Engineering Geographical Information Systems within the context of this research, is defined as:

An attribute of Zeus and Athene (or their Roman counterparts Jupiter and Minerva) usually represented as a goatskin shield.

(Oxford Dictionaries, 2010)

Minerva¹ is the Roman goddess of wisdom and sponsor of arts, trade and defence. Minerva has a special meaning for me for numerous reasons. She embodies the virtues of the acquisition and pursuit of knowledge through adversity, and I have included her as she links both Buckinghamshire New University and Coventry University through their common motto of 'Arte et Industria'.

¹ *The image is a detail from the Mosaic of the Minerva of Peace by Elihu Vedder, in the Library of Congress, Washington USA, photographed in 2007 by Carol Highsmith.*

Declaration

I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University.
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
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6. This thesis has been prepared in accordance with the Coventry University Academic Regulations version 2014, Section 8 and the Chicago Manual of Style (sixteenth edition).
7. I confirm that if the submission is based upon work that has been sponsored or supported by an agency or organisation that I have fulfilled any right of review or other obligations required by such contract or agreement.

Herbert Keith Winning

May 2015

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Publications

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WINNING, H. K. 2013. Pipeline Design - Protecting the Environment: Application of GIS to Pipeline Route Selection. Uganda Investment Forum - Driving Growth in Africa. Kampala, Uganda. 11th - 12th April: Commonwealth Business Council.

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WINNING, H. K. 2014b. Identifying Soil Erosion Risk for Onshore Pipelines. ESRI European User Conference. Split, Croatia. 13th - 15th October: ESRI.

WINNING, H. K. 2014c. PODS - From Design to Operation. PODS User Conference. Houston, USA. 25th - 27th October: Pipeline Open Data Standards.

WINNING, H. K. & COOLE, T. 2013. Explicit Friction Factor Accuracy and Computational Efficiency for Turbulent Flow in Pipes. *Flow, Turbulence and Combustion*, 90, 1-27.

WINNING, H. K. & COOLE, T. 2015. Improved method of determining friction factor in pipes. *International Journal of Numerical Methods for Heat & Fluid Flow*, 25.

WINNING, H. K. & HANN, M. J. 2014. Modelling Soil Erosion Risk for Pipelines Using Remote Sensed Data. *Biosystems Engineering*, 127, 135-143.

Nomenclature

Chapter 1

v_{mean}	Mean velocity (m/s)
c	Chézy roughness and conduit coefficient
H_r	Hydraulic radius
C_s	Conduit slope

Chapter 4

f_f	Fanning friction factor (dimensionless)
ε	Absolute Pipe Roughness (mm)
D	Pipe internal diameter (mm)
Re	Reynolds number (dimensionless)
f_d	Darcy or D'arcy-Weisbach friction factor (dimensionless)
r	Potential impact radius (m)
od	Outside diameter (mm)
p	Internal pressure (kPa)

Chapter 5

A	Mean annual soil loss ($t\ ha^{-1}$)
R	Mean annual rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}$)
K	Soil erodibility factor ($t\ ha\ h\ ha^{-1}\ MJ^{-1}\ mm^{-1}$)
S	Slope steepness factor (dimensionless)
L	Slope length factor (dimensionless)
C	Crop management factor (dimensionless)
P	Erosion control practice factor (dimensionless)
E	Kinetic energy per mm of rain ($MJ/ha.mm$)
I	Rainfall intensity (mm/h)
I_{30}	Maximum rainfall intensity over a 30 minute period multiplied by 2 (mm/h)
x	Slope length (m)
s	Slope gradient (percentage)
n	Slope steepness exponent (dimensionless)

Chapter 7

H_b	Heat transfer (W)
T_m	Logarithmic mean temperature of pipe segment (°C)
T_{p1}	Temperature of liquid entering pipe segment (°C)
T_{p2}	Temperature of liquid leaving pipe segment (°C)
T_s	Sink temperature, soil or surrounding medium (°C)
T_{soil}	Ambient soil temperature (°C)
L_{pipe}	Length of pipe segment (m)
R_i	Pipe insulation outer radius (mm)
R_p	Pipe outer wall radius (mm)
K_{ins}	Thermal conductivity of insulation ($W\ m^{-1}\ ^\circ C^{-1}$)
D_{cov}	Depth of cover to the pipe centreline (mm)
od	Outside diameter (mm)
ν	Viscosity of the liquid (cSt)
T	Absolute temperature (K)
h	Head (m)
f_d	Darcy or D'arcy-Weisbach friction factor (dimensionless)
D	Pipe inside diameter (m)
v_{mean}	Mean velocity (m/s)
g	Acceleration due to gravity (m/s^2)
P_{pump}	Pump power (kW)
Q_{pump}	Pump flow rate (m^3/hr)
H_{pump}	Pump head (m)
E_{pump}	Pump efficiency, decimal value less than 1 (dimensionless)
Sg	Liquid specific gravity (dimensionless)
γ	Ratio of specific heats of gas (dimensionless)
Q_{gas}	Gas flow rate (Mm^3/day)
T_1	Suction temperature of gas (K)
P_1	Suction pressure of gas (kPa)
P_2	Discharge pressure of gas (kPa)
Z_1	Compressibility of gas at suction conditions (dimensionless)
Z_2	Compressibility of gas at discharge conditions (dimensionless)
η_a	Compressor adiabatic (isentropic) efficiency, decimal value (dimensionless)
ΔT	Temperature rise (°C)
C_p	Specific heat capacity of the liquid ($J\ kg^{-1}\ K^{-1}$)

Appendix A

f_f	Fanning friction factor (dimensionless)
ε	Absolute Pipe Roughness (mm)
D	Pipe internal diameter (mm)
Re	Reynolds number (dimensionless)
f_d	Darcy or D'arcy-Weisbach friction factor (dimensionless)

Glossary

The page number of the first instance of the term is given in brackets.

Abstract Class	A class in object orientated programming that cannot have any instances. <i>See Feature Class.</i>	(114)
acLib	An internal suite of Visual LISP functions written by the author to support the development of the PIEE software. <i>See PIEE</i>	(113)
Activity diagram	An analysis model that depicts a process flow proceeding from one activity to another, similar to a flowchart, a defined chart type within the UML. <i>See UML.</i>	(134)
AEGIS	Advanced Engineering Geographical Information System. A single multi-discipline integrated system using an open industry standard schema providing all the standard GIS tools with the added functionality required to undertake the engineering and design of a specific engineering function. The instantiation of the AEGIS is called PIEE. <i>See PIEE.</i>	(i)
AFC	Approved for Construction. This is the final revision status of the design prior to construction.	(158)
AIC	Akaike Information Criterion. A measure of the fit of a statistical model to data, used to determine the accuracy and complexity of the model – a particular form of model selection criterion.	(58)
ALRP	ArcGIS Location Referencing for Pipelines. Provides core pipeline data management functionally of geometric and liner referencing within ArcGIS.	(105)
APDM	ArcGIS Pipeline Data Model. A pipeline specific GIS data model. <i>See ISAT and PODS.</i>	(105)
API	American Petroleum Institute.	(21)
ArcGIS	ESRI GIS software application. The software provides an infrastructure for making maps and geographic information available throughout an organisation, across a community, and openly on the Web. <i>See ESRI.</i>	(10)
ArcSDE	ESRI Spatial Database Engine is a server-software sub-system that enables the usage of Relational Database Management Systems for spatial data. The spatial data may then be used as part of a geodatabase. <i>See RDMS.</i>	(112)
ArcView	ArcView is the entry level of ArcGIS Desktop software by ESRI. <i>See ArcGIS and ESRI.</i>	(10)
ASME	American Society of Mechanical Engineers.	(21)

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer DEM. <i>See DEM.</i>	(93)
ASTM	American Society for Testing and Materials.	(141)
Attrition	The primary process of wind erosion, that creates the suspension of fine sediment particles. This process imparts an abrasive action on the soil surface and as the particles impact on the ground they tend to break into smaller particles.	(84)
AutoCAD	A commercial software application for 2D and 3D computer aided design (CAD) developed by Autodesk.	(xxviii)
bcma	Billion cubic metres per annum. A measurement of the volumetric flow rate of gas through a pipeline.	(xxix)
Black-box testing	Testing that ignores the internal mechanism of a system or component and focuses solely on the outputs generated in response to selected inputs and execution conditions. <i>See White-box testing.</i>	(169)
BoR	Book of Reference. This details all the potential owners and occupiers of land parcels along the pipeline route.	(158)
BS	British Standards.	(21)
BTC	Baku Tbilisi Ceyhan pipeline project. Transports crude oil from the offshore oil fields in the Caspian Sea to the Turkish coast on the Mediterranean, a distance of 1768 km.	(3)
CAD	Computer Aided Design.	(i)
CAE	Computer Aided Engineering.	(ii)
CAPEX	Capital expenditure. The capital cost of a project.	(10)
CGI	CAD/GIS Integration.	(i)
Chainage	The measure or distance along a linear feature from its origin. For pipelines, this is usually in the direction of fluid flow. <i>See Stationing.</i>	(105)
Class	A software module that provides both procedural and data abstraction. It describes a set of similar objects, called its instances.	(xxi)
CP	Cathodic Protection. The principle of cathodic protection is in connecting an external anode to the metal to be protected and the passing of an electrical DC current so that all areas of the metal surface become cathodic and therefore do not corrode.	(21)

Creep	The term given to the transportation of large (> 0.5mm dia.) soil particles, due to wind erosion.	(84)
Cyanobacteria	A photosynthetic bacterium, generally blue-green in colour and in some species capable of nitrogen fixation. Cyanobacteria were once thought to be algae. Also called blue-green alga.	(xxiv)
DEM	Digital Elevation Model. Digital representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals.	(12)
DESA	United Nations Department for Economic and Social Affairs.	(91)
Design Science	The paradigm within the discipline of Information Science that seeks to extend the boundaries of human and organisational capabilities, by creating new and innovative artefacts. <i>See Information Science.</i>	(i)
DGPS	Differential Global Positioning System. Differential correction techniques are used to enhance the quality of location data gathered using GPS receivers. The base station calculates and broadcasts corrections for each satellite as it receives the data. The correction is received by the roving receiver via a radio signal and applied to the position it is calculating. <i>See GPS.</i>	(12)
DosLib	A freeware library developed by Robert McNeel Associates.	(113)
DRA	Drag Reducing Agent. These long-chain hydrocarbon polymers decrease the amount of energy lost in turbulent formation. Using drag reducing agents enables pipeline operators to increase flow using the same amount of energy, or decrease the pressure drop for the same fluid flow rate.	(48)
DSRM	Design Science Research Methodology. Design science research focuses on the development and performance of (designed) artefacts with the explicit intention of improving the functional performance of the artefact.	(i)
EGIG	European Gas Incident Group. This group of 17 major gas transmission system operators in Europe gather data on the unintentional releases of gas in their pipeline transmission systems.	(73)
EOSAT	Earth Observation Satellite Company. Private company awarded ten-year contract to run the LANDSAT programme in 1985. <i>See LANDSAT.</i>	(10)
EPUG	ESRI European Petroleum User Group.	(105)

ESIA	Environmental and Social Impact Assessment. The formal process used to predict the environmental consequences (positive or negative) of a plan, policy, program, or project prior to the decision to move forward with the proposed action.	(11)
ESRI	Environmental Research Systems Institute. A company formed in 1969 by Jack Dangermond and one of the major developers of GIS software solutions.	(9)
EUROSEM	European soil erosion model. A mathematical model used for the estimation of soil loss. <i>See USLE.</i>	(88)
Eutrophication	The process by which pollution from such sources as sewage effluent or leachate from fertilised fields causes a lake, pond, or fen to become over rich in organic and mineral nutrients, so that algae and cyanobacteria grow rapidly and deplete the oxygen supply. <i>See Cyanobacteria, Leachate.</i>	(7)
Evapotranspiration	The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces, and by transpiration from plants.	(86)
FEA	Finite Element Analysis. A numerical technique for finding approximate solutions to boundary value problems for partial differential equations.	(9)
Feature Class	An object orientated programming class that can have instances, usually based on abstract class inheritance. <i>See Abstract Class.</i>	(104)
FEED	Front End Engineering Design. Basic engineering which comes after the conceptual design or feasibility study. The FEED identifies the technical requirements as well as rough investment cost for the project.	(11)
GIS	Geographical Information System. A system designed to store, analyse and manage geo-spatial data.	(i)
GPS	Global Positioning System. A satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense. GPS was originally intended for military applications, but in the 1980s, the government made it available for civilian use.	(xxiii)
GRI	Gas Research Institute.	(105)
Gryphon	Associated with mud volcanoes, these are small steep sided cones extruding mud during the dormant phase. <i>See Mud Volcano.</i>	(97)

GUID	Global unique identifier. It is a unique reference number used as an identifier. They are stored as 128-bit values, and are displayed as 32 hexadecimal digits with groups separated by hyphens within curly braces.	(127)
HCA	High Consequence Area. This is defined by ASME B31.8 as an area in location class 1 or 2 with potential concentrations of people. The extent of the HCA is determined by the PIR. <i>See PIR.</i>	(77)
HDD	Horizontal Directional Drill. A steerable trenchless method of installing underground pipes, conduits and cables in a shallow arc along a prescribed bore path by using a surface-launched drilling rig, with minimal impact on the surrounding area.	(19)
HSE	Health and Safety Executive. A non-departmental public body of the United Kingdom. It is the body responsible for the regulation and enforcement of workplace health, safety and welfare, and for research into occupational risks in England, Wales and Scotland.	(75)
Hypoxia	A reduction of oxygen in the water and rapid growth in algae; a result of eutrophication. <i>See Eutrophication.</i>	(7)
IEEE	Institute of Electrical and Electronics Engineers.	(110)
IGEM	Institution of Gas Engineers and Managers.	(49)
Information Science	The collection, classification, storage, retrieval and dissemination of recorded knowledge treated both as a pure and as an applied science.	(35)
ISAT	Integrated Spatial Analysis Techniques. A pipeline-specific data model. <i>See APDM and PODS.</i>	(105)
IT	Information Technology. The study or use of systems (especially computers and telecommunications) for storing, retrieving, and sending information.	(39)
ITT	Invitation to Tender. Initiating step of a competitive tendering process in which qualified suppliers or contractors are invited to submit sealed bids for construction or for supply of specific and clearly defined goods or services during a specified timeframe.	(12)
KPI	Key Performance Indicator. A set of quantifiable measures used to gauge or compare performance in terms of meeting strategic and operational goals.	(36)

Kriging	An interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points.	(42)
LANDSAT	The LANDSAT programme, conceived in 1965 by NASA with the first satellite launched in 1972 has provided over 40 years archived images of the Earth. <i>See NASA.</i>	(10)
Leachate	A product or solution formed by leaching, especially a solution containing contaminants picked up through the leaching of soil.	(xxiv)
LMTD	Logarithmic Mean Temperature Difference.	(139)
MAOP	Maximum Allowable Operating Pressure.	(74)
MapInfo	A desktop GIS software solution produced by Pitney Bowes Software (formerly MapInfo Corporation).	(10)
MMF	Morgan-Morgan-Finney. A mathematical model for predicting soil loss. <i>See USLE.</i>	(88)
Modelspace	One of the two primary spaces in which objects reside. Typically, a geometric model is placed in a three-dimensional coordinate space called modelspace. A final layout of specific views and annotations of this model is placed in paperspace. <i>See Paperspace & Viewport.</i>	(xxx)
MSE	Mean Square Error. This is equal to the square of the bias plus the variance of the estimator. If the sampling method and estimating procedure lead to an unbiased estimator, then the mean square error is simply the variance of the estimator.	(32)
MTO	Material Take Off. A list of all the materials required to accomplish the design.	(153)
Mud Volcano	A vent in the earth's surface through which escaping gas and vapour issue, causing mud to boil and occasionally to overflow, forming a conical mound around the vent. <i>See Gryphon.</i>	(97)
NASA	National Aeronautics and Space Administration. The United States government agency that is responsible for the civilian space program as well as for aeronautics and aerospace research.	(xxvi)

NDVI	Normalised Difference Vegetation Index. This is an index of plant photosynthetic activity. Active vegetation absorbs most of the red light, while reflecting most of the near infrared light. Vegetation that is dead or stressed reflects a greater amount of red light and less near infrared light.	(92)
Newtonian Fluid	A fluid exhibiting a linear relation between the applied shear stress and the rate of deformation.	(31)
NGO	Non-Governmental Organisation. A non-profit voluntary group, which is organised on a local, national or international level.	(37)
NIST	National Institute of Standards and Technology. An agency of the U.S. Department of Commerce.	(104)
NPSHa	Net Positive Suction Head Available. The absolute pressure at the suction port of the pump. <i>See NPSHr.</i>	(194)
NPSHr	Net Positive Suction Head Required. The minimum pressure required at the suction port of the pump to prevent cavitation. <i>See NPSHa.</i>	(194)
NTSB	National Transportation Safety Board. An independent Federal agency charged by Congress with investigating every civil aviation accident and significant accidents in other modes of transportation – railroad, highway, marine and pipeline, in the United States.	(74)
OD	Outer diameter.	(77)
OGC	Open Geospatial Consortium. An international industry consortium of companies, government agencies and universities participating in a consensus process to develop publicly available interface standards.	(105)
Olga	A dynamic multiphase flow simulator by Schlumberger, which models time-dependent behaviours, or transient flow, to maximise production potential of the system. Transient modelling is an essential component for feasibility studies and field development design.	(30)
OOP	Object Orientated Programming.	(114)
OPEX	Operational expenditure. The running costs throughout the operational phase of a project.	(10)
Paperspace	One of two primary spaces in which objects reside. Paperspace is used for creating a finished layout for printing or plotting, as opposed to doing drafting or design work. <i>See Modelspace & Viewport.</i>	(xxx)

Application and Development of AEGIS for Pipeline Design

PHMSA	Pipeline and Hazardous Materials Safety Administration. The department responsible for establishing national policy, setting and enforcing standards, and conducting research to prevent incidents, in the transportation of hazardous materials in the United States.	(3)
PIEE	Pipeline Integrated Engineering Environment. The instantiation of the AEGIS developed as part of this research. <i>See AEGIS.</i>	(ii)
PIM	Pipeline Integrity Management. A process for evaluating and reducing risks associated with the operation of pipelines.	(9)
PipeSim	A steady state, multiphase flow simulator used for the design and diagnostic analysis of oil and gas production systems developed by Schlumberger.	(30)
PIR	Potential Impact Radius. This is the radius within which, the potential failure of a gas pipeline could have significant impact on people or property and is dependent on the pipeline diameter and pressure. It is defined in ASME B31.8S.	(77)
PODS	Pipeline open data standards. A pipeline specific data model. <i>See APDM and ISAT.</i>	(101)
Polyline	An AutoCAD entity with multiple vertices, used to define a linear feature in three planes.	(117)
Python	Python is an interpreted, object oriented, high-level programming language with dynamic semantics.	(179)
RDMS	Relational Database Management System. <i>See ArcSDE</i>	(xxi)
REX	Rockies Express Pipeline. A 1698-mile gas pipeline from north-western Colorado to eastern Ohio transporting 1.8 billion cubic feet per day.	(107)
Rill	A shallow channel cut in the surface of soil or rocks by running water.	(82)
RoW	Right of Way. This comprises both the permanent pipeline easement and the extended corridor required to construct the pipeline.	(14)
RUSLE	Revised Universal Soil Loss Equation. A refinement of the USLE by Wischmeier and Smith in 1978. <i>See USLE.</i>	(88)
Saltation	The process of soil particle transportation due to wind erosion, where soil particles are initially lifted by the wind and then fall back to the ground as the gravitational forces exerted on the particles overcome their momentum.	(84)

Scaffolding code	Computer programs and data files built to support software development and testing but not intended to be included in the final product. <i>See Stub.</i>	(174)
SCP	South Caucasus Pipeline. Runs parallel to the BTC pipeline delivering Azeri Gas from the offshore Shah Deniz gas field into the Turkish gas transmission system for onward delivery to the European markets. It is designed to carry up to 7 bcma of natural gas. <i>See bcma.</i>	(3)
SCPX	South Caucasus Pipeline Expansion. Project to increase the flow rate of the SCP pipeline to 23 bcma. This requires 480 km of 48-inch diameter steel pipeline installed parallel to the existing SCP pipeline mostly in Azerbaijan as a looped line, as well as additional compression facilities in Georgia. <i>See SCP, bcma.</i>	(4)
SDS	Software Design Specification.	(ii)
Sediment	Solid fragments of inorganic or organic material that come from the weathering of rock and are carried and deposited by wind, water, or ice. <i>See Sediment Delivery.</i>	(5)
Sediment Delivery	The deposition of sediment at a specific location. <i>See Sediment.</i>	(xxix)
SERA	Soil Erosion Risk Assessment.	(32)
SHP	ESRI ArcGIS shapefile. A shapefile is a simple, non-topological format for storing the geometric location and attribute information of geographic features. Geographic features in a shapefile can be represented by points, lines, or polygons (areas).	(102)
Single-phase	A fluid that is in either a gaseous or liquid state, but not both.	(31)
SNR	Signal Noise Ratio. A measure of the ratio of the amplitude of the recovered GPS carrier signal to the noise. In a geodetic receiver the environment noise level is constant, so SNR corresponds directly to the GPS received signal strength. <i>See GPS.</i>	(12)
SOC	Soil Organic Carbon. This is the carbon stored within soil and is part of the soil organic matter, which includes other important elements such as calcium, hydrogen, oxygen, and nitrogen. Soil organic matter is made up of plant and animal materials in various stages of decay.	(5)
Spatial Autocorrelation	A measure of the degree to which a set of spatial features and their associated data values tend to be clustered together in space (positive spatial autocorrelation) or dispersed (negative spatial autocorrelation).	(42)

SPS	Synergi Pipeline Simulator. Hydraulic software to model a comprehensive range of pipeline assets including pipes, headers, valves, regulators, compressors/pumps, instrumentation, controllers, sensors and actuators.	(30)
SRTM DEM	Shuttle Radar Topography Mission. This was an international research effort that obtained digital elevation models on a near-global scale from 56° S to 60° N, flown in 2000. <i>See DEM.</i>	(93)
Stationing	The measure along a linear feature. For pipelines, this is usually in the direction of fluid flow. <i>See Chainage.</i>	(33)
Stub	Computer program statement substituting for the body of a software module that is or will be defined elsewhere. <i>See Scaffolding code.</i>	(174)
SWOT	Strength Weakness Opportunity Threat analysis. A structured planning method used to evaluate the strengths, weaknesses, opportunities and threats involved in a project or in a business venture.	(25)
TBM	Tunnel Boring Machine.	(159)
UML	Universal Modelling Language. Describes a set of standard notations for creating various visual models of systems, particularly for object orientated software development.	(110)
UNSD	United Nations Statistics Division.	(91)
USDA	US Department of Agriculture.	(90)
USLE	Universal Soil Loss Equation. A widely used mathematical model that describes soil erosion processes, developed in the United States by Wischmeier and Smith in 1965.	(32)
VBA	Microsoft Visual Basic for Applications.	(161)
Viewport	An AutoCAD entity created in paperspace to provide a view of the modelspace in the drawing. The use of viewports enables multiple views of the model that are scale, orientation and display independent. <i>See Modelspace & Paperspace.</i>	(155)
Visual LISP	A derivative of the LISP programming language specific to AutoCAD.	(160)
webGIS	A GIS designed for delivery across the internet or intranet. It includes server software to enable multi-user transactions, such as the ESRI ArcSDE software and an application-programming interface to serve geospatial data from a database. <i>See ArcSDE.</i>	(161)

White-box testing	Testing that takes into account the internal mechanism of a system or component. <i>See Black-box testing.</i>	(171)
WMO	World Meteorological Organisation. An agency of the United Nations.	(91)

Chapter 1

INTRODUCTION

This chapter introduces the field of pipeline engineering and provides the context for the research. It presents the historical development of onshore pipelines and the environmental issues facing the design and construction of today's large-diameter high-pressure pipelines. The chapter outlines the historical development of the computer-based systems used and presents a brief overview of the major phases of onshore pipelines, from the design and construction through to the management of the operational pipeline.

The basic design for any pipeline is governed predominantly by physical parameters relating to the chemistry and volume of the commodity to be moved, the distance it has to be moved (vertical as well as horizontal), the acceleration forces necessary to move it and its integrity during transportation (that is, without contamination or loss).

(Pipeline Industries Guild, 1984: 15)

Onshore pipelines can vary from short small-diameter pipelines for tie-ins or gathering lines, to large-diameter pipelines that transit countries. Although this research is equally applicable to the design of both systems, it is the design of these large high-value infrastructure projects that is primarily being addressed.

The design of these major projects is complicated for a number of reasons. Firstly, the number of interfaces: systems, data and disciplines. The number of interfaces increases the initial design time and reduces the ability to react quickly to design changes. Secondly, the spatial scale of these projects presents significant engineering, environmental and social challenges.

1.1 Development of Onshore Pipelines

Pipelines have played an important role in shaping our world for over 5000 years, originally transporting possibly the most precious commodity of all, water. Between 3000 and 2000 BCE, covered aqueducts and pipes of baked clay were being used in Mesopotamia (present day Iraq), copper pipes were being used in Egypt, and pipes made of bamboo and hollow logs were being used in China – where, in addition to water, gas was also being transported. During this early phase in pipeline engineering, the people of the Indus valley (present day Pakistan and Northern India) were using clay pipes of a standard size of approximately four-inch diameter by twelve-inch long (Antaki, 2003: 1) – this approach being an early example of the application of standards, a fundamental requirement in many fields of engineering, including pipelines.

Between 2000 and 1500 BCE, the Palace of Minos at Knossos in Crete was built using a system of spigot and socket earthenware pipes for water supply, drainage and waste water management (Fagan, 2011: 5). During the period of 1600 and 300 BCE, the Greeks continued to improve pipeline design through the use of an increasing range of pipeline materials including copper and lead, usually in a tapered pipe section similar to a current bell and spigot joint pipe (Antaki, 2003: 2).

However, it was the Romans between 400 BCE and 150 CE who really advanced pipeline engineering, with many of the techniques that they developed being unmatched until modern times. They made extensive use of aqueducts and fountains, which were used to mitigate pressure surges within the system. Bronze taps and fittings were increasingly being used and quality control marks were introduced on approved pipework. With the decline in the Roman Empire, the advances made were largely reversed during the middle ages (ibid: 2-3). In seventeenth and eighteenth century Europe, cast iron pipelines were being used and mathematicians devised formulae to predict fluid flow in pipes and channels. Because these early formulae were written to determine the flow characteristics of water, they did not include the properties of viscosity and density of the fluid. An early flow equation devised by Chézy in the 1770s is given as

$$v_{mean} = c(H_r C_s)^{0.5} \quad (Eq. 1.1)$$

Equation 1.1 Chézy Flow Equation (Culvern, 1983: 1)

Where (v_{mean}) is the mean velocity, (c) is the Chézy roughness and conduit coefficient, (H_r) is the hydraulic radius and (C_s) is the slope of the conduit. This formula is still accurate,

although subsequent work has further refined the value of (c) , while also determining that (c) is probably also affected by the velocity, thereby making this an implicit function.

With the advent of the Industrial Revolution in the nineteenth century, the requirements for steam, water, distribution of natural gas and the emerging oil industry provided the impetus for growth. During this period, there were numerous advances in material technology, fabrication methods and standardisation, which enabled the use of pipelines of increasing length and size. Along with the advances in materials, the engineers' understanding of the fluid mechanics involved in the design of these systems was increasing. The basic requirement of any pipeline system has remained unchanged over the last 5000 years, encompassing elements of mechanical, civil, chemical and environmental engineering.

In a global market, the need to be able to manufacture in cost-effective locations and efficiently transport goods to the best markets requires a reliable and secure energy infrastructure in which pipelines play a major role. In 2003, there were over 3.7 million kilometres of pipelines in the U.S. carrying natural gas and hazardous liquids (PHMSA, 2003)², while there are currently almost 16000 kilometres of oil and gas pipelines in the UK (Department of Energy & Climate Change, 2013).

Modern transmission pipelines, such as the Baku Tbilisi Ceyhan (BTC) and the South Caucasus Pipeline (SCP) pipelines, present significant engineering and environmental challenges due to their size and length. The environmental impact throughout the life cycle of the pipeline is being seen as an increasingly key issue in the oil and gas industry (Morgan, 2005: 155) and this is particularly true in areas of difficult or poor terrain, such as experienced in Azerbaijan (Winning, 2013a).

The BTC Pipeline transports crude oil from the offshore fields in the Caspian Sea to the Turkish port of Ceyhan on the Mediterranean coast, a distance of 1768 km, all of which is buried. With a diameter of 42 and 46-inches, it has the capacity of delivering one million barrels of oil per day. In addition to the pipeline, there are eight pump stations, two pigging stations, one pressure reduction station and 101 block valves; the total installed cost for this pipeline was \$3.9 billion (Pitt, 2006). The SCP pipeline, which runs parallel to the BTC pipeline, transports Azeri Gas from the offshore Shah Deniz gas field into the Turkish gas transmission system, for onward delivery to the European markets. It was initially designed to carry up to 7 billion cubic metres annually (bcma) of natural gas. The system comprises

² *Pipeline and Hazardous Materials Safety Administration.*

691 kilometres of 42-inch diameter steel pipeline, two compressor stations, one intermediate pigging station and eleven block valves (BP, 2012); the total installed cost was \$1 billion (GOGC, 2007). The routes of the BTC and SCP projects are shown in Figure 1.1.

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Figure 1.1 – BTC and SCP Pipeline Projects

The SCP Expansion (SCPX) project is a \$2 billion investment to increase the flow rate of the SCP pipeline to 23 bcma (Dadashova, 2013). In order to achieve this, 480 kilometres of 48-inch diameter steel pipeline will be installed parallel to the existing SCP pipeline, mostly in Azerbaijan as a looped line, with additional compression facilities in Georgia. The SCPX route is shown in Figure 1.2.

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*Figure 1.2 – SCPX Pipeline Project
(SCP Company, 2013: 3)*

1.2 Environmental Issues

While pipelines represent the most efficient and environmentally sound method of transporting fluids over long distances, they also present significant environmental challenges.

Pipeline development inevitably results in economic, social and environmental change, both positive and negative. It is the responsibility of the pipeline promoters, construction contractors and government to manage such developments in a manner that ensures minimal negative impact and maximum sustainability.

(Swan, 2009: 34)

Although there are numerous environmental challenges facing the design and construction of onshore pipelines, possibly the greatest is that presented by soil erosion, which is why it has been singled out in this research.

On the basis of its temporal and spatial ubiquity, erosion qualifies as a major, quite possibly the major, environmental problem worldwide.

(Toy et al., 2002: 1)

The effects of soil loss worldwide are a major concern; it affects the environment, food security and public health (Bandara et al., 2001, Pimentel, 2006). It is estimated that 75 billion metric tons of soil worldwide are lost per annum, with Africa, Asia and South America typically experiencing average losses of 30 to 40 tons per hectare per annum ($t\ ha^{-1}\ year^{-1}$) (Pimentel et al., 1995: 1117).

Within the global context, soil erosion has a significant impact on the environment: it causes environmental damage through sedimentation, pollution and increased risk of flooding. In addition, eroded soils may lose up to 75 per cent of their carbon content, leading to emission of carbon to the atmosphere (Morgan, 2005: 9). However, sedimentologists tend to argue that the soil organic carbon (SOC) is buried and protected by the sediment and therefore the effect on atmospheric carbon dioxide is less than that claimed by some soil scientists (Lal, 2005: 137). Irrespective of the argument, the loss of SOC due to soil erosion is generally accepted, as is the impact this has on the levels of atmospheric carbon dioxide.

Apart from the societal costs, soil degradation and loss due to erosion has significant economic impact. The cost to the US economy is estimated to be between US\$30 billion (Uri and Lewis, 1998: 53) and US\$44 billion (Pimentel et al., 1995: 1120-1121) annually,

while the annual cost in the UK is estimated at £106 million (Pretty et al., 2000: 113). In Indonesia, the cost is estimated at between US\$341 and US\$406 million per year in Java alone (Magrath and Arens, 1989: 54). These costs result from the combined effects of both on-site and off-site impacts due to soil erosion.

On-site impacts include the loss of soil function from the breakdown of the soil structure and the reduction in organic matter. The result is reduced yields, loss of arable land, reduced food security (Cohen et al., 2006: 250) and risk to existing infrastructure such as roads, railways and pipelines (Pimentel et al., 1995: 1120).

Off-site effects due to the transportation and deposition of sediment include the increased turbidity in watercourses, which can seriously impact on public health, and a risk to hydrological infrastructure, such as hydroelectric generation and irrigation schemes, primarily due to increased wear on bearings and abrasion damage to impellers and pumps (Morgan, 2005: 1).

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*Figure 1.3 – Caspian Sea showing Eutrophication
(NASA, 2003)*

With increased turbidity comes the potential for eutrophication, which is the response of aquatic systems to raised levels of nitrates or phosphates. This leads to hypoxia, a reduction of oxygen in the water and rapid growth in algae (Ekholm and Lehtoranta, 2011, Vollenweider, 1970). An example of this is the northern section of the Caspian Sea, where eutrophication of the northern part of the sea is due to soil erosion washing nitrates and phosphates into the Volga and Ural rivers (Leroy et al., 2007: 3360). This is shown in Figure 1.3 as the green/blue area in the northern part of the Caspian Sea.

In Europe, this is being addressed in part by the introduction of the European Water Framework Directive (2008), which outlines national responsibilities for water quality and places a legal responsibility on landowners to prevent pollution of water sources due to soil erosion.

Although soil loss is a natural process it is greatly increased by anthropogenic activity impacting on land management practices, such as farming and construction (Montgomery, 2007: 13268). In order to understand the impact of anthropogenic activity on continental erosion, Wilkinson and McElroy examined both long-term and short-term data on rates of sediment transfer in response to glacio-fluvial and anthropogenic processes. They found that the greatest rates of soil loss prior to the influence of anthropogenic agents were associated with the Pliocene epoch (5.3 to 2.6 million years ago), which had estimated rates of soil loss of $1.4 \text{ t ha}^{-1} \text{ year}^{-1}$. From this they concluded that a sustainable rate of soil loss would be less than $1.5 \text{ t ha}^{-1} \text{ year}^{-1}$ (2007: 155).

Although there are numerous environmental challenges in the construction of these large transmission pipelines, soil erosion is one of the major ones. Apart from the costs associated with remedial re-instatement work, failure to manage this can lead to the exposure of the buried pipeline (Morgan et al., 2003: 249) causing the pipeline to free span, which can lead to catastrophic failure due to cyclic loading or vortex-induced vibrations (Gao et al., 2006: 291) (Yang et al., 2008: 301). While this is generally more of an issue with offshore pipelines and onshore pipelines at river crossings, onshore pipelines exposed due to soil loss exhibit the same problems (Figure 1.4).



Figure 1.4 – Free Spanning Pipe Due to Soil Erosion (Georgia)

While many of the environmental challenges on a pipeline project can be mitigated to some extent through good construction management, soil erosion is largely a product of the installation method of the pipeline and the soil conditions, and therefore can only be minimised through the use of the correct erosion control methods (Morgan, 2005: 170). This is especially important in areas of highly erodible soils, such as are encountered in Azerbaijan (Figure 1.5).



Figure 1.5 – Gully Erosion in Highly Erodible Soils (Azerbaijan)

In order to minimise this risk, a number of techniques are employed. During the design phase of the project, the soil erosion risk factor is determined based on data collected in the field. From this, the soil erosion control measures for the route are defined and the bio-restoration scope of work prepared. During construction, the reinstatement is monitored to ensure that it is carried out in accordance with design, with any additional local requirements as directed by the construction environmental engineer. Once construction is completed and the line is commissioned and handed over to the operator, the operator will continue to monitor the asset for the duration of its operating life using a Pipeline Integrity Management (PIM) system. Where areas of soil erosion are identified, remedial action is taken to ensure the integrity of the pipeline, which may require the addition of river training works, berms, additional jute matting and further bio-restoration techniques (Morgan et al., 2003).

1.3 Computer Based Design

All forms of computer-based design including CAD, CAE and GIS are relatively recent developments. The first issue of the AutoCAD design software was in 1983 and it was not until the early 1990s that CAD came to dominate the drawing board across the broad range of engineering disciplines. While the use of spatial analysis might not be as established as pipeline engineering, it can certainly trace its roots back to 1854, and Snow's work on determining the cause of cholera – which was based on the spatial analysis of those infected with the disease (Snow, 1857).

These three forms of computer-based design have evolved largely independently of each other because they seek to address different problems. CAD enables the modelling and representation of objects and designs in 2D and 3D, usually to enable construction or manufacture. CAE is used for numerically intensive computation such as finite element analysis (FEA), and stress and hydraulic analysis as part of the design process, while GIS enables the analysis, query and representation of geospatial data.

Since the introduction of GIS, it has gone through several stages of development and refinement. The 1960s and 1970s saw the development of the early GIS systems, which were highly influenced by the individuals' active in the field during this period, such as Jack Dangermond – who in 1969 founded the Environmental Research Systems Institute (ESRI), of which he is still Chief Executive Officer. The second phase up to the early 1980s saw the involvement of national agencies and evoked wider interest, with countries outside the United States becoming involved. The 1980s saw increasing commercial exploitation of

GIS, with MapInfo being formed in 1986, and the ESRI ArcView³ and ArcGIS⁴ products being released in 1995 and 1999 respectively. Since then the field is increasingly more user-dominated, with emphasis being placed on standards and data interoperability (Coppock and Rhind, 1991: 39).

The rise in the use of GIS is also a result of the increasing availability and decreasing cost of data acquisition. The Landsat programme, conceived in 1965 with the first satellite launched in 1972 has provided over 40 years of archived images of the Earth; and this unparalleled data archive gives scientists the ability to assess changes in the Earth's landscape. However, in 1985 the programme was transferred into the private sector when the Earth Observation Satellite Company (EOSAT) was awarded a ten-year contract to run it. The result was the granting of exclusive rights to market the Landsat data to EOSAT (NASA, 2014).

By 1992, it had become clear that the high cost of commercially provided Landsat data was restricting its use in research and other public sector applications. In response, the U.S. Congress passed the *Land Remote Sensing Policy Act of 1992* into law in September of that year. This law established a new national land remote sensing policy and led to renewed use of this data for research (Gabrynowicz, 1993).

The use of all three computer based design systems is fundamental to the design of pipelines, which has led to the issue of interoperability between disparate systems. While the systems themselves do not necessarily need to be interoperable, and their data might be stored in different formats, to share information across systems requires data interoperability.

1.4 Pipeline Design

The optimum design for a pipeline is one which satisfies all the code requirements, minimises the balanced Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) costs, and minimises the impact on society and the environment (Menon, 2004: 214).

Determining the optimum route is complicated due to confounding, as the determinants of the optimised route interact with each other (Menon, 2005: 328). The shortest route between two points is the least cost solution with respect to CAPEX for the pipeline material costs.

³ *ArcView is the entry level of ArcGIS Desktop software by ESRI.*

⁴ *ESRI GIS software application. The software provides an infrastructure for making maps and geographic information available throughout an organisation, across a community, and openly on the Web.*

However, changes in elevation along the route or the geology of the terrain traversed significantly increase both CAPEX and OPEX costs due to pumping/compression requirements or construction costs (Boyd and Campbell, 1983: 238) (Mohitpour et al., 2003: 12). In addition to this, environmental and social factors further complicate the determination of the final route, especially as it is not always possible objectively to quantify the cost impact of these factors.

Most major infrastructure projects typically follow a sequence of phases, with the design being refined at each stage. Initially, a pre-feasibility study will be conducted to identify a potential corridor for the pipeline, which could be between 5 and 10 kilometres in width depending on the length of the pipeline. The study will include some high-level preliminary hydraulics in order to determine a possible diameter, wall thickness and pumping/compression requirements in order to provide the preparation of a preliminary cost estimate.

If the project is deemed viable from a financial and engineering perspective, a full feasibility study will be conducted. This builds on the work carried out in the pre-feasibility study and is frequently conducted by different consultant engineers to provide a further check on the pre-feasibility study. This study will seek to identify the major constraints for the route corridor: environmental, social, security and constructability. At this stage, some local input will be used – which can be a combination of the use of in-country engineering and environmental specialists or site visits. The feasibility study will produce a reduced corridor width, typically of 1 km, a refined hydraulic analysis and more detailed cost estimates. If the project is still deemed feasible then it will move into the next phase.

Front End Engineering Design (FEED) follows with further refinement of the route based on a preliminary route walk. This phase will look in some detail at the method of engineering, design and construction of the pipeline. An Environmental Social Impact Assessment (ESIA) will be prepared, a fundamental requirement for subsequent phases, in order to gain funding and host government approval. At this stage, a preliminary route centreline is identified.

Following on from FEED is the detail design phase, during which the design is finalised. Where detailed vector mapping is not available, high-resolution satellite imagery and a digital elevation model (DEM) is acquired. A detailed survey of the proposed pipeline centreline is carried out using a Differential Global Positioning System (DGPS)⁵ survey. Where the Signal Noise Ratio (SNR)⁶ of the DGPS is such as to render the survey out of tolerance, or in areas where the level of accuracy required is greater than can be achieved using the DGPS method, surveys are carried out using total stations.

Final hydraulic modelling will be conducted to ensure that the line is optimised, and further environmental surveys conducted. At some point during this phase, an Invitation to Tender (ITT) package will be prepared for the construction of the pipeline. The bids are then evaluated and the successful bidders notified; any changes in the design during the bidding process are communicated and costs finalised.

During this stage, the orders for long lead items such as compressors, pumps, valves and line pipe will be placed, land ownership along the pipeline route will be identified, and negotiations with landowners initiated. Any deviations in the route from that submitted to the authorities in the construction application permit will be notified. This design process is shown in Figure 1.6.

⁵ *Differential correction techniques are used to enhance the quality of location data gathered using GPS receivers. The base station calculates and broadcasts corrections for each satellite as it receives the data. The correction is received by the roving receiver via a radio signal and applied to the position it is calculating.*

⁶ *A measure of the ratio of the amplitude of the recovered GPS carrier signal to the noise. In a geodetic receiver the environment noise level is constant, so SNR corresponds directly to the GPS received signal strength.*

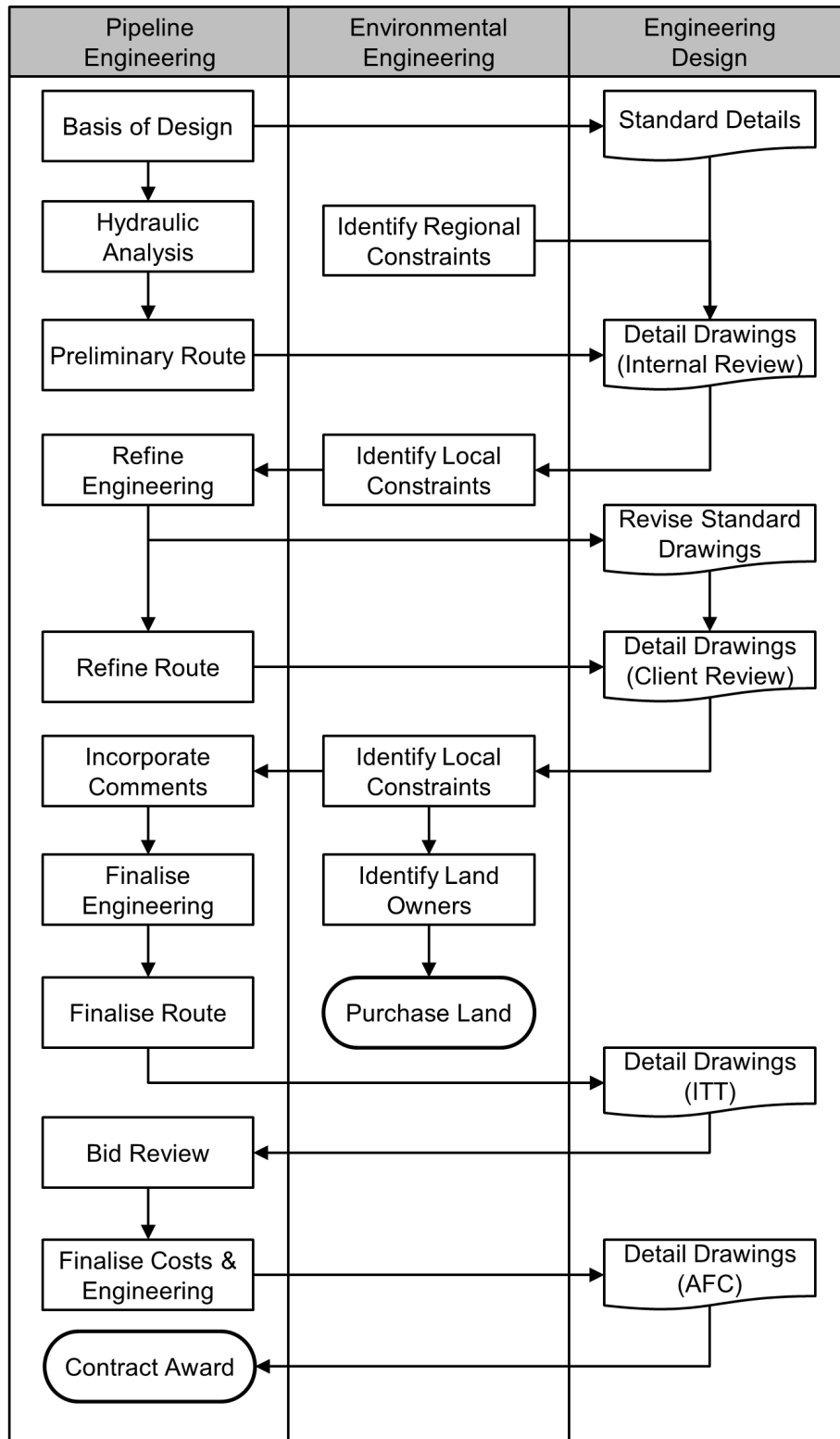


Figure 1.6 – Simplified Pipeline Design Flowchart

1.5 Pipeline Construction

Pipeline construction always complies with the relevant national, state and company standards, as specified by the documents detailing the design of the pipeline (Menon, 2011: 57). While the sequence described can vary slightly, it covers the major phases of the construction of a typical pipeline (Figure 1.7).

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*Figure 1.7 – Typical Pipeline Construction Sequence
(Gulf South Pipeline Company, 2013)*

1.5.1 Survey and Stacking (Stage 1)

Prior to construction, the pipeline centreline and right of way (RoW) is surveyed and physically marked, ensuring that the construction does not deviate from the land that has been purchased/leased for the installation of the pipeline.

1.5.2 Front-End Clearing (Stage 2)

Any pre-construction environmental requirements such as the need to establish a seedbed are then carried out. Finally, the RoW is cleared of brush, trees and large rocks.

1.5.3 Right of Way Preparation (Stage 3)

The final RoW preparation is to remove and stack the top soil to one side of the RoW, leaving a running track for the construction of the pipeline. Figure 1.8 shows the balance between engineering and the environment that good construction practice can provide. A reduced working width for a short length has enabled the preservation of an isolated mature tree on the RoW without the need to increase the pipeline length and introduce additional bends.



Figure 1.8 – Right of Way Preparation (UK)

1.5.4 Stringing (Stage 4)

The linepipe and any induction/hot bends or fittings are then transported from the pipe storage yards to the pipeline spread – induction bends are small radius bends (typically with a radius of five times the pipe diameter) that are formed in the pipe mill. This requires good logistics so that the spread material requirements are met, thereby ensuring that there are no delays while minimising the impact of the construction traffic on the local area (Figure 1.9).



Figure 1.9 – Pipe Stringing (Georgia)

1.5.5 Bending (Stage 5)

Although some of the bends on the pipeline are induction bends, the majority of the bends are formed on the spread as cold bends using a bending machine with bending sets and mandrels for the required pipe diameter (Figure 1.10). Cold bends typically have a radius of 40 times the pipe diameter. Some contractors will perform the cold bending operations in a pipe yard and then transport the formed bends to the spread – a method that requires a model of the pipe trench to be created for the bending engineer to set the bends correctly.



Figure 1.10 – Pipeline Bending (Georgia)

1.5.6 Welding (Stage 6)

Once the bending is complete, the pipe segments are lined up on wooden skids or soil stacks and clamped. The front end welding crew perform the first weld pass – called the root pass – and then move onto the next joint. They are then followed by the main welding crew, who complete the weld, including the final cap weld. Figure 1.11 shows the front end welding crew applying the root pass weld, with the wooden skid visible in the background. The roughness of the weld is not considered in hydraulic modelling given that the welds typically represent some 0.2% of the total line length.

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*Figure 1.11 – Pipeline Welding (Canada)
(CEPA, 2013)*

1.5.7 Trenching (Stage 7)

The trench for the pipeline is then prepared and the excavated material (subsoil) stacked in order to avoid contamination with the topsoil. Where rock is encountered, additional trench depth is required so that a fine granular bed can be put into the bottom of the trench in order to ensure that the pipe coating will not be damaged when the pipe is lowered in. This phase is sometimes carried out prior to the welding. Figure 1.12 shows a trench machine preparing the trench prior to the welding of the linepipe.

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Figure 1.12 – Trenching (Australia)
(TSA, 2014)

1.5.8 Coating and Inspection (Stage 8)

Although the pipe is delivered to the pipe yard coated, the field joints and any areas where the coating has been damaged during the construction process are field coated, typically using either fusion-bonded epoxy (FBE) or a layered heat-shrinkable sleeve to ensure that the pipe coating protection is complete. Prior to coating, the pipe is cleaned by grit blasting and primed to ensure that the surface is free of any mill scale and corrosion contaminants (Figure 1.13).

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Figure 1.13 – Field Joint Coating
(EPC, 2013)

1.5.9 Lowering-In (Stage 9)

The pipe is lifted using side booms and the pipe suspended over the trench prior to being lowered in. Immediately after this, the as-built survey crew will record the location and elevation of all welds, fittings and bends as part of the as-built documentation. Figure 1.14 shows the installation of an open cut river crossing. The pipe has been concrete coated for buoyancy control and mechanical protection.



Figure 1.14 – Pipeline Lower and Lay (Georgia)

1.5.10 Backfill (Stage 10)

The backfill crew will then backfill the trench ensuring that adequate padding is placed around the pipe to prevent mechanical damage to the pipe coating. Before completing the backfill, any land drains that have been cut during construction will be repaired and documented.

1.5.11 Tie-In and Testing (Stage 11)

The pipeline is then hydrostatically tested in sections to ensure the pipeline integrity. For sections constructed using trenchless methods such as Horizontal Directional Drills (HDD), the testing is carried out prior to installation, as shown in Figure 1.15.



Figure 1.15 – Hydro Testing (UK)

1.5.12 Right of Way Reinstatement (Stage 12)

All construction debris is removed and the RoW graded to the pre-construction contours. Topsoil is then replaced allowing for settling over the trench. Surface drainage and any additional erosion control measures such as berms that may be required to protect the exposed RoW on steep slopes are installed.



Figure 1.16 – Newly Reinstated Pipeline RoW (UK)

Figure 1.16 shows the pipeline RoW with the topsoil graded immediately prior to the final re-instatement. Permanent pipeline markers, aerial markers and Cathodic Protection (CP) test posts are installed and all temporary access to the RoW removed or re-instated to pre-construction condition or better. Finally, the exposed RoW is reseeded and planted with native species.

1.6 Pipeline Operation

Critical to the safe operation of these pipelines is the pipeline integrity (Muhlbauer, 2004: 259). PIM is ensured through constant monitoring and inspection of the pipeline system but the most critical phase is the initial design. Good design of these complex systems is fundamental to PIM of the system.

PIM is a regulatory requirement for operating pipelines and is set out in ASME B31.8⁷, API 1160⁸, BS PD 8010⁹ and other codes. During the operational life of the pipeline, the operator is required to monitor and document the pipeline for defects, corrosion loss, mechanical damage and, maintenance or repair of the pipeline. This data is used to perform risk assessments of the asset, support regulatory compliance and provide the operator with a maintenance schedule. This data and other information relating to the pipeline (including all the components and installation records) are stored in a GIS system, with links to a document management system for additional supporting records and documentation. It is for this reason that the development of GIS systems for pipelines have largely focused on the management of existing assets rather than on facilitating the design of new pipelines.

1.7 The Challenge

The design of major onshore pipelines is a complex engineering activity involving input from various disciplines, each with different demands often competing against one another. The value of these projects in a world of increasing energy use is clear, as is the potential for major environmental damage in the event of rupture of the pipeline. Therefore, the safe operation of these major assets is paramount – and this is dependent on safe design and the quality and completeness of the as-built data for PIM. Increasing awareness of the impact to

⁷ *American Society of Mechanical Engineers.*

⁸ *American Petroleum Institute.*

⁹ *British Standards.*

the environment from major infrastructure construction projects is driving change through the industry and encouraging the design engineer to find better environmental solutions.

In order to address these challenges and improve on the current methods used, an integrated design solution is required. This would enable engineers across different disciplines using different software to use the same data to undertake their design activities, with the analysis and results generated thereby being made available to the wider project. This approach would reduce the initial design time and the number of interfaces, leading to improved data interoperability. A common standard for data storage of engineering and geospatial data across the different systems would enable the design information to be used throughout the entire life cycle of the pipeline, from design through construction, commissioning, operation and decommissioning.

Chapter 2

THESIS STATEMENT

This thesis has evolved through a combination of experience gained in working within the field of onshore pipeline design for over 25 years and research in the fields of pipeline hydraulics, soil erosion and engineering design.

The chapter sets out the research question, which in turn defines the scope of the research. An assessment of the methods currently used in the design of onshore pipelines was conducted in order to identify those aspects that, according to the research question, warranted inclusion in the literature survey. The aim of the preliminary literature survey was to validate the value of the proposed research question and, in conjunction with the research scope, defined the aim, objectives and success criteria of the research. Finally, it provided the framework for the literature review (Chapter 3) and the subsequent supplementary literature reviews (Chapter 4, 5 and 6).

2.1 Research Question

What are the design challenges for long onshore pipelines and how can the design process be modified to improve the quality of the engineering, environmental, design and as-built data, while reducing the cost and schedule impacts?

2.2 Research Scope

The research scope sets out the constraints for the literature survey (Section 2.4), the results of which are used in conjunction with the scope to define the aim and objectives of the thesis (Section 2.5).

From the research question, the scope of the research is defined by:

- identifying the key disciplines and functions of the design process and the interfaces between these components
- identifying the design challenges for long distance onshore pipelines by function
- identifying the elements of the design process which have most impact on cost or schedule

The three key disciplines of the pipeline design process are pipeline engineering, environmental engineering and engineering design, which together account for the significant proportion of the design process. These disciplines are distinct from one another, they have different reporting structures, and they require different skills and underpinning knowledge.

Regarding cost and schedule, the key challenges during the design phase for long distance onshore pipelines, grouped by discipline, are:

- Pipeline Engineering:
 - early identification of the optimum hydraulic route and line size configuration
 - automated production of schedules, reports and material take offs (MTOs)
 - reduction in the checking requirement of design documents

- Environmental & Social:
 - early identification of environmental and social issues to influence design
 - correlation of ESIA commitments to design documentation
 - cost and time required for field verification studies

- Engineering Design:
 - management of change
 - quality and data integrity of the design documents
 - design freeze time – due to the time required to create or revise the key design deliverable documents
 - checking requirement of design documents
 - production of large quantities of linear referenced drawings

In addition to the three disciplines identified, a further function of the pipeline design process is the functional requirement for as-built documentation, which is critical for the operation of the pipeline. This comprises design, vendor, construction, and commissioning data. Because of the wide range of data from different sources that need to be collated, checked and rationalised, this aspect of the pipeline design frequently lacks the quality and data integrity that the pipeline operator requires for PIM.

The key challenges for as-built documentation are defined as:

- ensuring the quality and data integrity of the design, vendor and as-built records
- reducing the time delay from mechanical completion to delivery of the as-built documentation for commissioning
- the production of quality as-built documentation to support PIM during operations

2.3 Review of Current Method of Pipeline Design

To refine the research scope further prior to conducting the literature survey, a review of the current methods used in pipeline design (outlined in Section 1.4) were evaluated. Initially a SWOT analysis (Figure 2.1) was carried out on the current method used for the design of pipeline projects. From this, a number of possible opportunities and threats were identified.

Strengths	Weaknesses
<ul style="list-style-type: none"> • Established industry standard process • Mature systems • No additional training required 	<ul style="list-style-type: none"> • Number of discipline interfaces • Number of systems • Data interoperability issues • Slow iterative processes
Opportunities	Threats
<ul style="list-style-type: none"> • Reduced design cost • Improved data usage • Reduced interfaces • Integrated multi-discipline system 	<ul style="list-style-type: none"> • Competitors developing integrated solutions • Low cost centre engineering solutions

Figure 2.1 – SWOT Analysis of Current Pipeline Design Methodology

According to the SWOT analysis, the greatest potential threat to a company using the current methods for pipeline design is posed by the increasing use of low cost engineering centres to perform the engineering design and from competitors developing integrated systems. The SWOT analysis identifies that there is little to be gained in continuing with the current approach other than that the process is established and mature. Perhaps more importantly, the analysis identifies that both the weaknesses and opportunities are functions of the information systems that the processes use rather than the processes themselves.

Based on the opportunities identified, the key features for the AEGIS system and the reason for their selection were identified (Table 2.1).

Feature	Reason for Selection									
	Reduced Interfaces	Interoperability	Codes & Standards	Environmental	Route Selection	Cost Modelling	Increased efficiency	Improved quality	Reduced design cost	Improved PIM Data Quality
Preliminary hydraulic analysis within the GIS environment	✓	✓			✓	✓	✓		✓	
Location class for gas pipelines	✓		✓		✓	✓	✓	✓	✓	
Identification of the potential soil erosion risk	✓			✓	✓	✓	✓		✓	
Production of alignment sheets		✓	✓		✓		✓	✓	✓	
Web hosted GIS model	✓	✓					✓			
As-built documentation		✓					✓	✓		✓
PIM GIS Model	✓	✓	✓							✓

Table 2.1 – Selected Features for the AEGIS

Based on the selected features for the AEGIS shown in (Table 2.1), the functional ownership was identified and the relationship of the function to the role of the pipeline engineer, environmental engineer and engineering designer mapped in the form of a use case diagram (Figure 2.2). The PIM GIS Model identified in the table resides in the ‘Set System Parameters’ function in the use case diagram. The function of the suitability of the model for PIM during the operational phase is largely dependent on the choice of the database schema so that it will comply with the pipeline operators’ requirements, which might be industry or company specific.

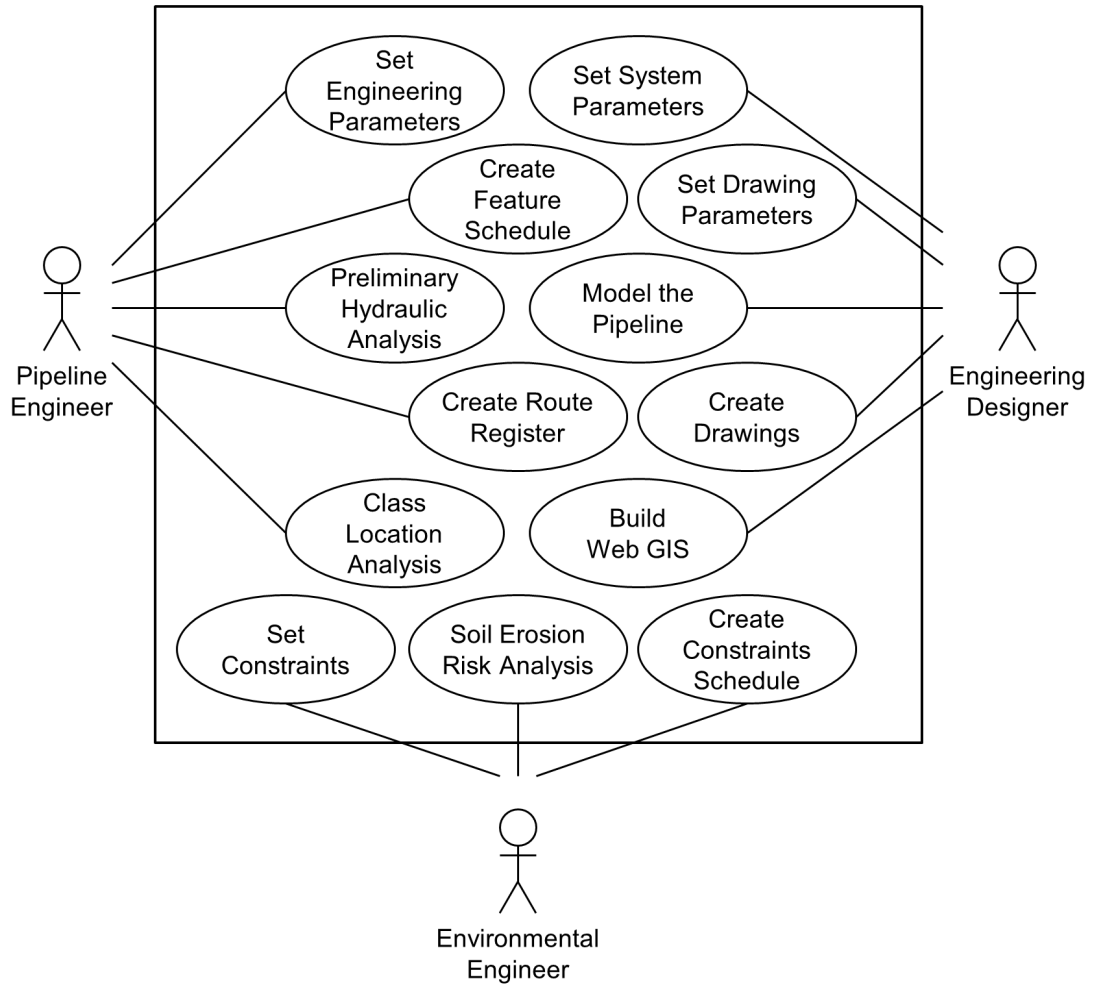


Figure 2.2 – AEGIS/PIEE Use Case Diagram

2.4 Literature Survey

Given the breadth of material to be covered across multiple disciplines, a preliminary literature survey was conducted to validate the research question. Even where research is not so wide-ranging, a preliminary survey enables a more targeted and structured approach to the final literature review.

The difference between a literature survey and a literature review is the difference between report and critique.

(Rugg and Petre, 2004: 69)

The aim of the literature survey was to confirm the research potential of the research question and to set the parameters for a more detailed review of the literature. The disciplines, current methods and systems used in the field of onshore pipeline design were

reviewed and the major challenges facing the design and construction of major onshore pipeline projects summarised in Chapter 1.

The disciplines with the greatest influence on pipeline design are pipeline engineering, environmental engineering and engineering design, with the dominant systems in engineering design being CAD and GIS. For each of the three disciplines, an individual relevance tree diagram was created mapping out the areas that should be considered for the literature review. Once all the individual relevance tree diagrams were created, areas of synergy between the different disciplines were identified. In order to define the scope, not only for the literature reviews but also for the development of the system, some of the areas for research were discarded at this stage. The criterion used for this selection process was to retain those areas of research that would develop the features selected for inclusion in the AEGIS (Table 2.1) and that would demonstrate:

- synergy across discipline boundaries
- application of GIS to solving engineering problems
- application of GIS to determine regulatory or code requirements
- use of an industry open standard database schema
- reduction in the number of interfaces
- improved data interoperability
- ability to produce automated engineering design deliverables
- quality assurance (QA) / quality control (QC) of the model

2.4.1 Pipeline Engineering

The primary function of pipeline engineering is to identify the optimum pipeline route. In order to achieve this, it is necessary to satisfy a number of criteria, which include:

- optimum line size and pump/compressor station requirements
- minimisation of the environmental and social impact of the project
- balancing the CAPEX and OPEX
- constructability
- compliance with all regulatory requirements, codes and standards

Central to the route selection is the hydraulic analysis of the route. This both confirms the ability of the proposed design to meet the flow requirements and defines some of the major inputs to the cost model. This is currently an iterative process because the hydraulic analysis

is performed using specialist software such as PipeSim, Olga or Synergi Pipeline Simulator (SPS), with the route being defined using a combination of CAD and GIS. This requires the route profile to be exported from the CAD/GIS model after each route revision for input into the hydraulic analysis software.

The current method suffers from a number of limitations. While the data is the same for both systems, there is no data interoperability between the systems. This is further compounded by the fact that the pipeline route usually needs simplifying in order for the hydraulic analysis software to be able to handle the data, because the number of nodes that it can handle is limited. Typically, a pipeline model of 500 km can have over 30000 elevation points. In order to minimise the run-time of the hydraulic solution the number of nodes on the pipeline profile need to be reduced to approximately 1000, producing a simplified elevation profile. Even so, solution times for the hydraulic analysis can take several hours. Given the uncertainty of some of the model parameters, such as pipe roughness and simplified elevation data, software vendors are concentrating on improving the performance, rather than addressing the need for more complex models.

As part of the hydraulic analysis, high points may be identified on the pipeline route, which, if reduced could offer cost savings. However, as the hydraulic analysis only views the pipeline in profile, there is no way for the hydraulic engineer to know if a re-route to reduce the high point is feasible, because he cannot see the constraints or adjacent features. This requires the proposed point to be passed back to the CAD/GIS engineer to try to identify another route, and the process repeated until an acceptable hydraulic route is identified.

By incorporating the preliminary hydraulic analysis into an integrated CAD/GIS system, the number of interfaces would be reduced, as would the time taken to identify hydraulically feasible routes. Given the combined computational overhead of GIS systems and numerically intensive hydraulic modelling, an efficient method of performing this high level preliminary hydraulic modelling would be required.

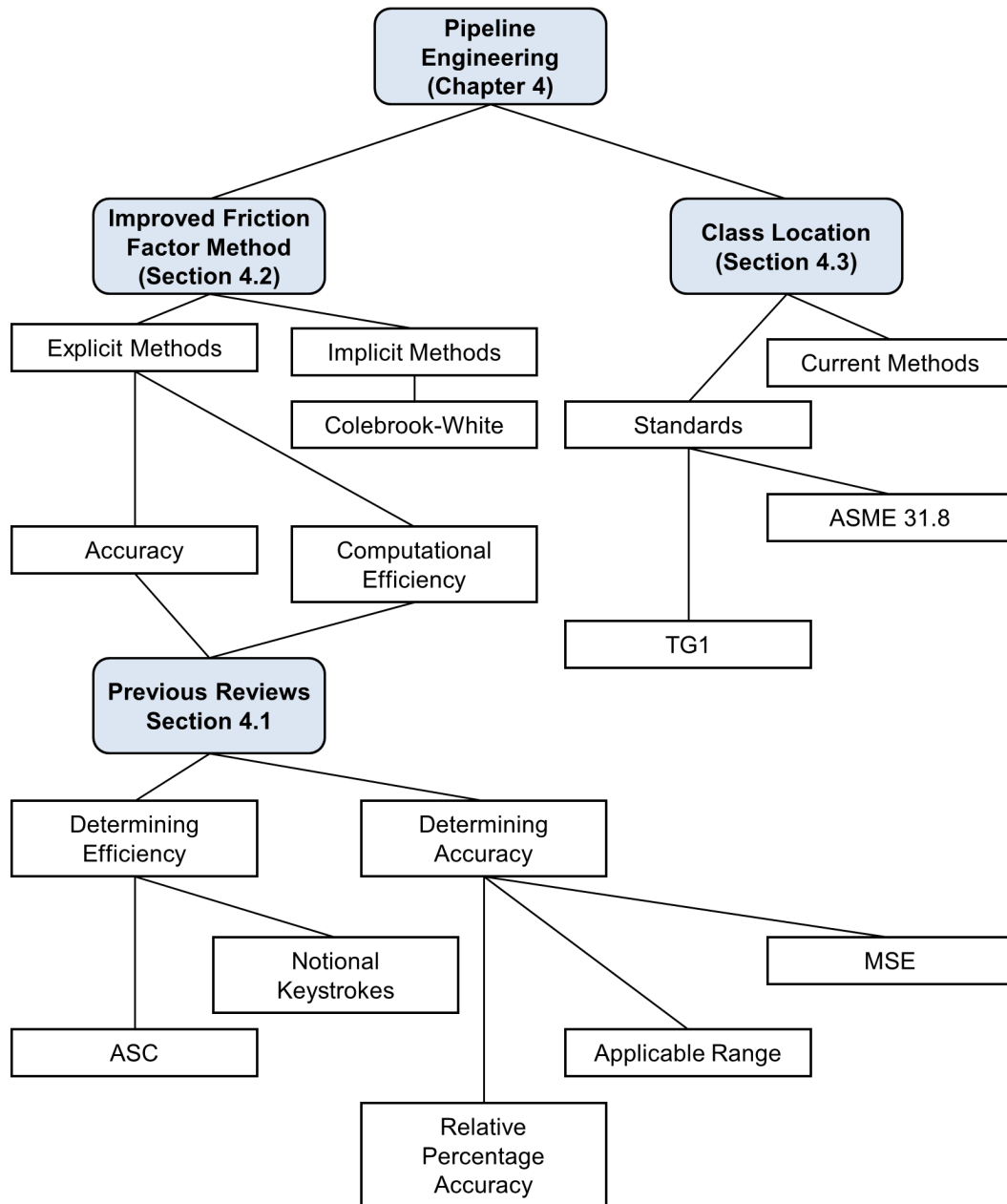


Figure 2.3 – Pipeline Engineering Literature Review Relevance Tree Diagram

During the initial survey, the importance of reviewing and establishing the most computationally efficient method for determining the friction factor for pipelines was identified. As the area of research is concerned with large-diameter major oil and gas transmission pipelines, the review would be restricted to the estimation of the friction factor for single-phase Newtonian¹⁰ pipelines. The determination of the accuracy of the equations would involve comparing the results to the implicit Colebrook-White equation using both the

¹⁰ A fluid that is in either a gaseous or liquid state, but not both and which exhibits a linear relation between the applied shear stress and the rate of deformation.

mean square error (MSE) and mean relative percentage error to enable comparison to the previous reviews. However, the determination of the computational efficiency would require a departure from the previous reviews in that it would use a computational rather than a statistical or notational keystroke method for the evaluation. The outcome of the literature survey for pipeline engineering is shown in the relevance tree diagram (Figure 2.3).

Another area for review was the determination of location classes for gas pipelines. Although the scope for this is limited as it is a code requirement, it was felt that this should be included within the study for a number of reasons. Firstly, it has a CAPEX cost impact on the project; and secondly, it could be done accurately and repeatedly within a GIS model, offering an improvement over current methods. This demonstrates the value of using GIS for solving geospatial engineering problems.

2.4.2 Environmental Engineering

While there are a number of environmental challenges for large pipelines, the one that has the greatest potential for the integrity of the pipeline and therefore OPEX cost is post-construction soil erosion. In order to improve on the current methods employed, it was proposed to perform an early screening survey using remote sensed data. As this would need to be carried out during the initial route selection phase of the project, this placed both time and cost constraints on the data available for analysis.

In order to determine the individual factors for the Universal Soil Loss Equation (USLE), including rainfall erosivity and soil type from remote sensed data, a review was required of the soil erosion process, erosion control methods for pipelines and the determination of storm events. This was necessary because the temporal aspect for construction sites varies from the methods required for general land management.

This analysis would enable the early identification of areas of potential soil erosion risk, thereby allowing this important factor to be considered in the initial route selection process. Additionally, it would enable the subsequent field validation of the soil erosion risk to be targeted, further reducing schedule impact and cost. The results of the literature survey for the application of soil erosion risk assessment (SERA) to the AEGIS are shown in the relevance tree diagram (Figure 2.4).

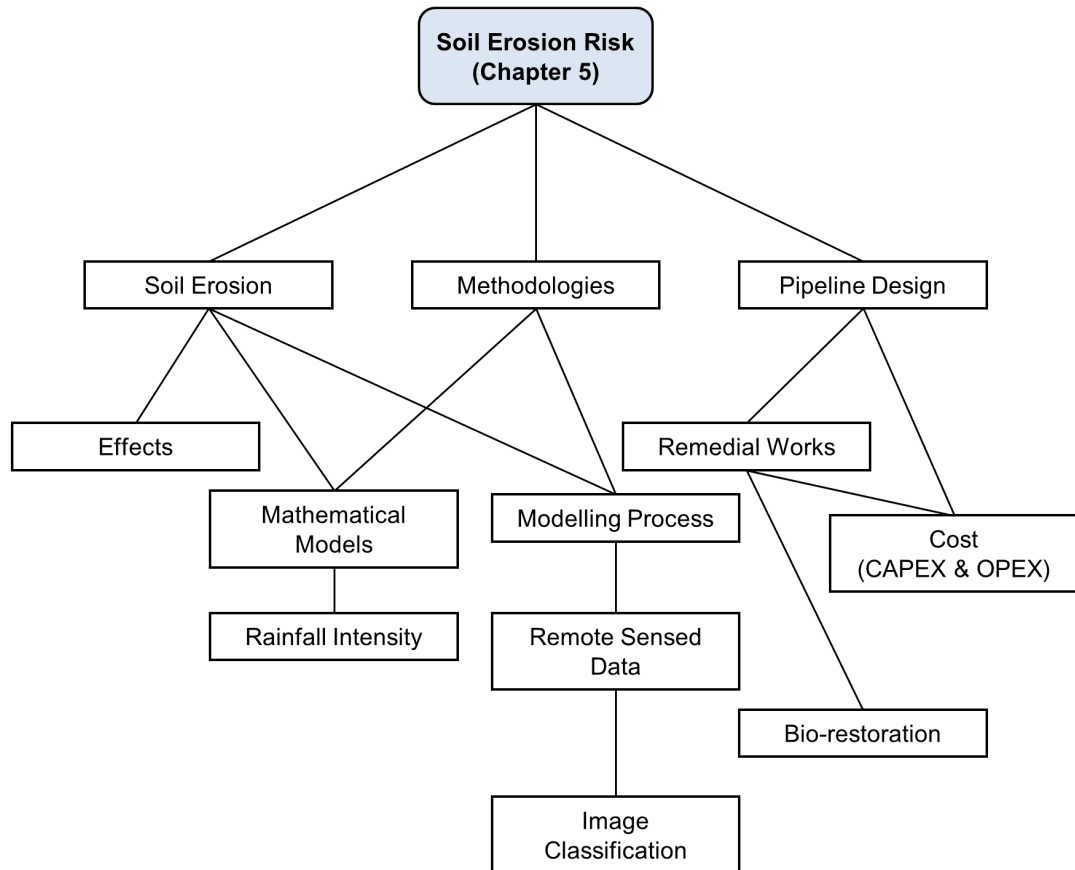


Figure 2.4 – Soil Erosion Literature Review Relevance Tree Diagram

2.4.3 Engineering Design

The key requirement for pipeline design with respect to engineering design is the efficient production of the key deliverables that define the scope and requirements for the construction of the pipeline – the main deliverable being the alignment sheets (Appendix E). These drawings show the proposed pipeline route in plan and profile with all the relevant engineering information – including pipe size and wall thickness, minimum depth of cover, location of third party and physical crossings, CP requirements, geotechnical investigation locations, and environmental and construction constraints. These drawings are usually produced at a plan scale of 1:2500 showing one kilometre on each drawing, and therefore for major pipelines there can be several hundred or even thousands of these drawings made in the course of a project. As the drawings are sequential, any changes to the route can have a significant impact on the following drawings due to the use of stationing¹¹ to reference

¹¹ The measure along a linear feature. For pipelines, this is usually in the direction of fluid flow.

features on the pipeline. To minimise this and to produce the drawings as efficiently as possible, it is usual to use proprietary or in-house developed software.

A review of the proprietary systems for the production of alignment sheets is given in Chapter 8. However, all the current systems only provide functionality for the creation of alignment sheets. They do not enable the user to create other types of drawings or to undertake engineering or environmental analysis. The outcome of the literature survey and the scope of the subsequent literature review for the engineering design components of the AEGIS are shown in the relevance tree diagram (Figure 2.5).

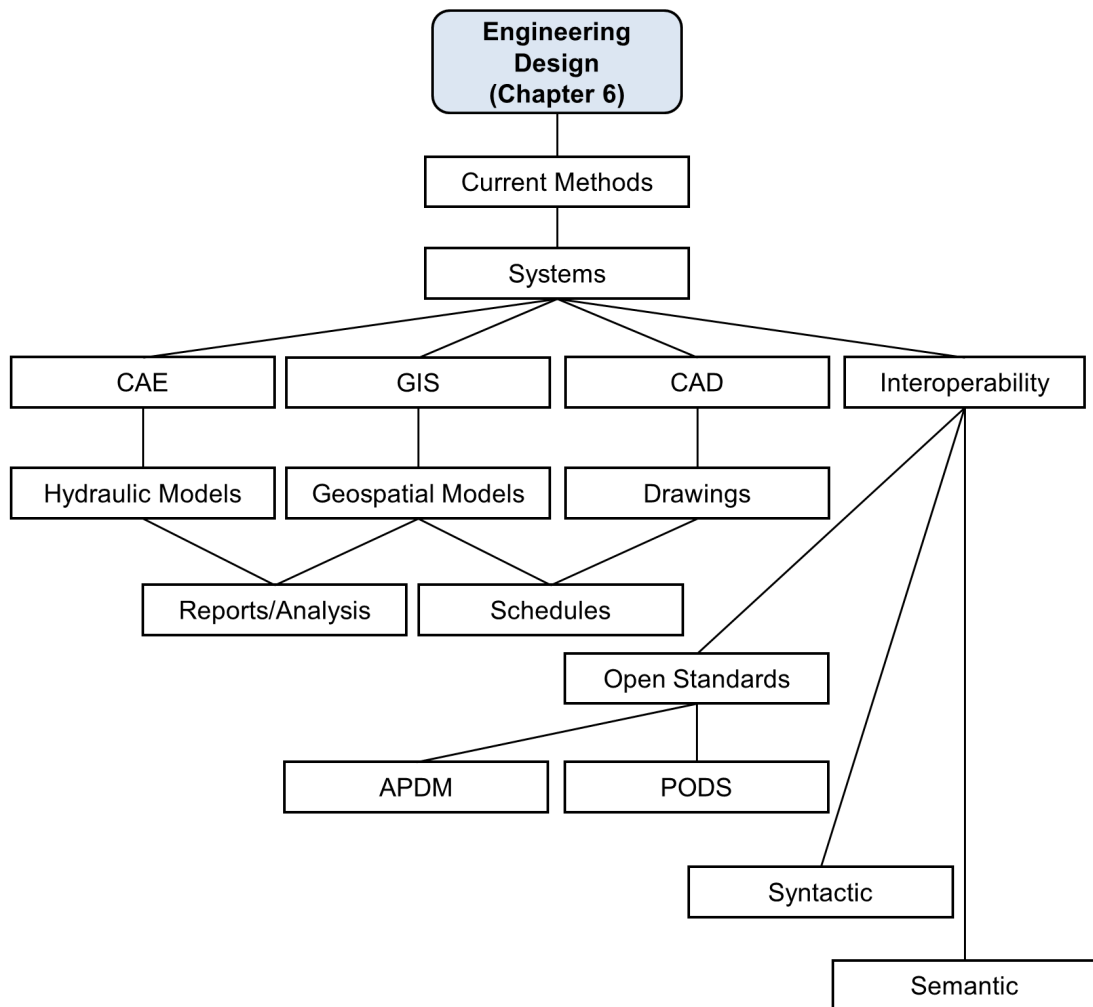


Figure 2.5 – Engineering Design Literature Review Relevance Tree Diagram

2.5 Aim and Objectives

The literature survey revealed a number of problems concerning onshore pipeline design: range of computer systems, data sharing, user requirements and expectations, existing functional and organisational workflows, performance, and schedule requirements. These problems span a range of disciplines and their solution would require a combination of quantitative and qualitative research methods together with a wide range of evaluation methods. Because of this requirement, the research has been undertaken from an information science perspective based primarily on the design science methodology, which is discussed in detail in Chapter 3.

Although leading GIS practitioners have identified the potential for the application of GIS to engineering design (Longley et al., 2010: 190), this does not appear to be a view widely shared by pipeline engineers and was a significant absence in the literature review. The uptake of GIS varies widely across different engineering fields, ranging from environmental engineering and transportation, which have developed specialist GIS systems, to pipelines where the development of the specialist geospatial database schemas are relatively recent having only been developed over the last 10 years. Central to this thesis is the development of the AEGIS. In the absence of an accepted definition, the final section in this chapter defines this key term.

2.5.1 Aim

The aim of this research is to develop a multi-disciplinary system for the design of onshore pipelines and to evaluate the effectiveness of this approach compared to current methods.

While it is not within the ambit of this research to develop a complete model, the key elements of each of the identified disciplines must be included if an evaluation of the methodology can be conducted. Furthermore, the model would have to include examples of computationally intensive calculations, requirements due to code compliance and the application of geospatial analysis to solve engineering problems within an engineering environment.

2.5.2 Objectives

In order to operationalise the research aim, a number of specific research objectives have been identified:

Research Objective 1: Define the methodology for the research.

Research Objective 2a: Review existing explicit equations for estimating the friction factor in single-phase Newtonian fluids for accuracy and computational efficiency.

Research Objective 2b: Identify the possibility of defining a computationally more efficient explicit equation without sacrificing accuracy.

Research Objective 2c: Develop a GIS method for the determination of pipeline wall thickness for populated areas against the code requirements of ASME B31.8.

Research Objective 2d: Develop a GIS method for the dynamic estimation of soil erosion risk for onshore pipelines using remote sensed data.

Research Objective 2e: Review the use of open data standards and the data interoperability issues for computer systems.

Research Objective 2f: Review the challenges and issues of CGI.

Research Objective 3: Produce a SDS for the AEGIS.

Research Objective 4: Develop and evaluate the AEGIS.

2.6 Success Criteria

The success of the research can be determined by a number of key performance indicators (KPIs):

- reduction in the number of interfaces
- improved data interoperability
- the ability to perform high level pipeline hydraulics within a GIS system
- an improved method for the determination of the location classes for onshore gas pipelines that is more efficient, is repeatable, and enables the engineer to identify the impact of different code requirements
- early consideration of the soil erosion risk and potential bio-restoration strategies for the pipeline
- improved accuracy and speed of production of the alignment sheets and other design documents

Though the KPIs provide metrics for the evaluation of the system (i.e. they determine the success of the research), the success of the thesis is in part based on its originality and its contribution to the canon of knowledge (QAA, 2011: 32). During the course of this research, a number of peer-reviewed journal papers have been published and conference papers presented. The publications were targeted towards a range of audiences ranging from a high level presentation to government ministers, heads of non-governmental organisations (NGOs) and business leaders (Winning, 2013a), to technical papers presenting new methods and processes for fluid mechanics (Winning and Coole, 2015) and environmental engineering (Winning and Hann, 2014).

The following is a list of journal papers published and conference papers presented during the course of the research, grouped by the chapter to which they relate:

Chapter 4

WINNING, H. K. & COOLE, T. 2013. Explicit Friction Factor Accuracy and Computational Efficiency for Turbulent Flow in Pipes. *Flow, Turbulence and Combustion*, 90, 1-27.

WINNING, H. K. & COOLE, T. 2015. Improved method of determining friction factor in pipes. *International Journal of Numerical Methods for Heat & Fluid Flow*, 25.

Chapter 5

WINNING, H. K. 2013. Pipeline Design - Protecting the Environment: Application of GIS to Pipeline Route Selection. Uganda Investment Forum - Driving Growth in Africa. Kampala, Uganda. 11th - 12th April: Commonwealth Business Council.

WINNING, H. K. & HANN, M. J. 2014. Modelling Soil Erosion Risk for Pipelines Using Remote Sensed Data. *Biosystems Engineering*, 127, 135-143.

WINNING, H. K. 2014b. Identifying Soil Erosion Risk for Onshore Pipelines. ESRI European User Conference. Split, Croatia. 13th - 15th October: ESRI.

Chapter 6 and 7

WINNING, H. K. 2014a. Developing Advanced Engineering Geographical Information Systems for Pipelines. ESRI European Petroleum User Group Conference. London, UK. 6th - 7th November: ESRI.

WINNING, H. K. 2014c. PODS - From Design to Operation. PODS User Conference. Houston, USA. 25th - 27th October: Pipeline Open Data Standards.

2.7 Advanced Engineering Geographical Information Systems

The term ‘Advanced Engineering Geographical Information System’ first appeared in the glossary of a standard GIS text (Longley et al., 2010: xvii). However, although they introduced the term, they did not define it and it is interesting to note that though it appears in the glossary, it is not mentioned elsewhere in the text. In addition, the term AEGIS fails to return anything in internet search engines or online journals, which would suggest that perhaps the authors saw this as an aspirational future direction for GIS challenging engineers to see the potential for the application of GIS within their own fields.

Since all GIS systems are designed to store, manage, retrieve, and perform queries on geospatial data, an engineering GIS would need to do this with geospatial engineering data. However, to be ‘advanced’ it must be more than merely a repository for geospatial engineering data; it must be capable of performing analytical and decision-making functions within an engineering context while presenting the engineer with all the geospatial tools and functionality inherent in a GIS. In the absence of a formal definition for an AEGIS, it must provide the following functionality as a minimum:

- all the standard GIS functionality for geospatial data management, access, querying and analysis
- a method of handling engineering data, including revision and versioning control of datasets
- specialist engineering geospatial and non-geospatial tools that are specific to the particular field of engineering within the GIS environment
- a reduction in the interfaces between processes and the provision of data interoperability

Based on these requirements, an AEGIS may therefore be defined as follows:

A single multi-discipline integrated system using an open industry standard schema providing all the standard GIS tools with the added functionality required to undertake the engineering and design of a specific engineering function.

The key element of this definition is that the system should be function and not discipline specific.

Chapter 3

METHODOLOGY

Essential to this thesis is the development of a multi-disciplinary system for the design of onshore pipelines. As the thesis focuses on an integrated multi-disciplinary approach, so too must the methodology (**Research Objective 1**). The first section presents a literature review of the methodologies used within the disciplines of information science, information technology (IT) and GIS within the context of the current research. Fundamental to this is the epistemological argument concerning what constitutes a science – a recurrent theme spanning these relatively new disciplines.

The following sections present and discuss the selected methodologies for the main areas for research identified in Chapter 2. They also set out the methodology for the design, development and evaluation of the AEGIS itself.

3.1 Literature Review

Science may be defined as

The intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment.

(Oxford Dictionaries, 2010)

Whereas from an epistemological perspective, it may be stated succinctly as

Science is a structure built upon facts.

(Davies, 1968: 8)

What constitutes a fact from a scientific perspective and how scientific law should be defined (Chalmers, 1999: 3) is itself a complex matter and the subject of much debate. However, Chalmers asserts that there is a common agreement within the scientific community concerning what constitutes a scientific fact namely the following:

- (a) Facts are directly given to careful, unprejudiced observers via the senses.*
- (b) Facts are prior to and independent of theory.*
- (c) Facts constitute a firm and reliable foundation for scientific knowledge.*

(ibid: 4)

This concept that science is derived from facts forms the basis for the inductivist view of science. Through induction, facts acquired through observation are translated into laws and theories which provide predictions and explanations through the process of deduction (ibid: 53-54). There are a number of problems with this inductivist view of science. Given a finite number of observations, any law or theory will make claims for an infinite number of cases. Therefore, the probability that any given law is valid is a finite number of observations divided by infinity, which is zero (ibid: 52).

In response to the limitations of this view, Popper proposed an alternative view in *The Logic of Scientific Discovery*, usually referred to as the 'falsification' hypothesis. Essential to this is the premise that all scientific theories can in principle, be falsified by future observations that refute their hypotheses, regardless of their predictive and explanatory value up to the present time. In the 1960s, Kuhn challenged both the inductivist and falsificationist views of science in *The Structure of Scientific Revolutions*. He proposed a paradigm that followed an open-ended scheme (Figure 3.1).

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Figure 3.1 – Kuhn’s Scientific Revolution

Initially there is diverse and disorganised activity (Pre-science) which becomes progressively more structured until the stage is reached of ‘normal science’, characterised by a widely accepted and dominant paradigm. During the stage of ‘normal science’, the application and predictive value of the paradigm grows. This is the work of many, who are largely uncritical of the potential problems with the paradigm, which is a necessary requirement if they are to be focused on expanding its application. Where there are a significant number of anomalies or there is an anomaly of a fundamental nature, then confidence in the paradigm is reduced and the crisis stage of the cycle begins. This leads to increasingly divergent research that becomes less constrained by the paradigm, leading to the proposal of new paradigms. Once a dominant rival paradigm emerges, and it is increasingly accepted the period of revolution is attained, with the whole cycle progressing as before.

Without digressing into a major epistemological debate, it is important to understand that there is no universally accepted philosophical definition of what constitutes science. Therefore, the debate within the disciplines of information science, IT and GIS concerning whether they are sciences is complicated by this underlying question.

However, what constitutes knowledge, and hence the methods for acquiring it, rests on basic assumptions regarding ontology (i.e., what we believe to exist) and epistemology (i.e., how beliefs are acquired and what justifies them).

(Sjoberg et al., 2007: 359)

GIS, IT and information science are all relatively new disciplines. GIS in its current form as a computer-based system dates from the 1960s (Coppock and Rhind, 1991: 21), although the underlying science of spatial autocorrelation¹² predates it by at least 100 years (Snow, 1857). A significant body of the published material into research methods for these disciplines seeks to address the fundamental question of the disciplines' place as a science in comparison to the natural sciences. This is due to the prestige and value attached to science in modern society and the perception that only science can produce theoretical knowledge (March and Smith, 1995: 252). Irrespective of the validity of this opinion, the epistemological debate within these disciplines is important because it directly affects the research methods that are seen as acceptable within the research community:

Though not intrinsically harmful, this division of interests has created a dichotomy among IT researchers and disagreement over what constitutes legitimate scientific research in the field. Such disagreements are common in fields that encompass both knowledge-producing and knowledge-using activities.

(ibid: 252)

Although GIS may be regarded as both a tool and a science, this is an overly simplistic view. Wright et al. propose a taxonomy that has three positions along a continuum from tool to science, with an intermediate position of tool-making (1997: 354). In the context of GIS as a tool, the research focuses on the substantive problem (ibid: 355); however, depending on the audience of the research, a description of the application of the tool may not even be relevant. In the tool-making context, the development of the tool is inseparable from the substantive problem. This work is generally undertaken within the commercial rather than the academic sector and generally does not lead to publication due to the proprietary nature of the development (ibid: 356). The science of GIS however, is the underpinning concepts to enable the analysis and modelling of geospatial data. This ranges from the geometric primitives of points, lines and areas to topological relationships and interpolation techniques such as kriging¹³ (ibid: 357). This view of GIS as a continuum is supported by others (Pickles, 1997: 364), though the complexity of this approach is greater than a simple

¹² *A measure of the degree to which a set of spatial features and their associated data values tend to be clustered together in space (positive spatial autocorrelation) or dispersed (negative spatial autocorrelation).*

¹³ *An interpolation technique in which the measured values are weighted to derive a predicted value for an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points.*

semiotic gesture (Chrisman, 1999: 182). The use of GIS as a tool may require some minor elements of tool-making and, conversely, the act of tool-making will generally require validation through the use of accepted tools; the science of GIS is not on some ethereal plane of ideas and concepts, but firmly tied to choices of data and method (ibid: 182).

However, (Johnston, 1986) takes a broader view of what constitutes science; he states that science may be considered to be:

... the pursuit of systematic and formulated knowledge, and as such is not confined to any particular epistemology.

(ibid: 6)

Applying this broader definition of science, the concept of a continuum from tool to science through tool making applies equally well to the disciplines of IT and information science.

March and Smith suggest that the scientific interest in IT is either descriptive or prescriptive (1995: 252). The descriptive research is seen as producing knowledge corresponding to natural science (Hempel, 1966: 103) and is analogous to the science end of the GIS continuum. Prescriptive research aims at improving IT performance through the application of knowledge corresponding to design science (Simon, 1996: 135), akin to the tool-making process in GIS.

Information science is an applied research discipline that draws on theories from disparate disciplines to solve problems that share interfaces between individuals, organisations and IT. Early research in information science tended to be dominated by a positivistic experimental approach (Kaplan and Duchon, 1988: 573) that attempted to provide a quantitative method, objectivity and testability by reducing context, although this reduced the understanding of the process (ibid: 572). Research methods within the information science discipline may be characterised as belonging to one of two paradigms – either behavioural science or design science. Both are fundamental to the information science discipline because it requires interaction between users, organisations and technology (Hevner et al., 2004: 75). Behavioural science develops and verifies theories that explain and predict the behaviour of organisations and individuals, whereas the design science paradigm advances individual or organisational capabilities by improving and creating information systems. While the dominant paradigm has been that of behavioural science, the value of the design science approach is increasingly being recognised:

While design, the act of creating an explicitly applicable solution to a problem, is an accepted research paradigm in other disciplines, such as engineering, it has been employed in just a small minority of research papers published in our own best journals to produce artefacts that are applicable to research or practice.

(Peppers et al., 2007: 45)

Peppers et al. reinforce the design science approach and its applicability to engineering by stating that:

Engineering disciplines accept design as a valid and valuable research methodology because the engineering research culture places explicit value on incrementally effective applicable problem solutions.

(2007: 45)

Design science consists of four key elements: constructs, models, methods and implementations. Central to design science is the creation of a physical artefact intended to perform the task (March and Smith, 1995: 253) and to attain goals (Simon, 1996: 133):

In much of the computer science literature it is realized that constructs, models, and methods that work "on paper" will not necessarily work in real world contexts. Consequently, instantiations provide the real proof.

(March and Smith, 1995: 262)

Within design science, the instantiation or artefact is seen as critical to evaluating the constructs, models, methods (Hevner et al., 2004: 100) and process automation (Nunamaker Jr and Chen, 1990: 93).

March and Smith state that IT research needs to be grounded in both the utility of design science and the theory of natural science (1995: 255). Based on this, they proposed a research framework linking research activities to research outputs (Figure 3.2).

		Research Activities			
		Build	Evaluate	Theorise	Justify
Research Outputs	Constructs				
	Model				
	Method				
	Instantiation				

Figure 3.2 – Research Framework in Information Technology

(March and Smith, 1995: 255)

Peppers et al. propose a fuller DSRM process model (Figure 3.3). The model is structured with the problem-centred approach as the basis of the nominal sequential order, though the process may be initiated at a number of different start points. The approach (2007: 58) proposed by Peppers et al. forms the basis of the overall methodology for this thesis (Figure 3.3).

This process model provides a holistic methodology for the thesis, with the creation and evaluation of the artefact being essential. Chapters 4 and 5 require this methodology to support the development and evaluation of the theories they propose. The following sections discuss the methods selected for these key topics of the thesis.

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*Figure 3.3 – Design Science Research Methodology Process Model
(Peppers et al., 2007: 58)*

3.2 Pipeline Engineering

3.2.1 Review of Explicit Friction Factor Equations

One of the major constraints for the route selection is the hydraulic analysis of the pipeline. Pipeline hydraulic simulation is an iterative process requiring specialist software and a detailed knowledge of hydraulics by the engineer carrying out the analysis. The performance of a preliminary hydraulic analysis of the pipeline route within a GIS environment will not remove the need for this detailed analysis to be undertaken. The benefit of this approach will be to potentially reduce the number of early iterations and enable a quick comparison between different route options.

In order to incorporate hydraulic modelling into the GIS model, the major challenge will be to achieve computational efficiency, because hydraulic analysis requires a very large number of iterative calculations to establish the frictional pressure loss within the system. There are a number of explicit equations for the approximation of the friction factor and there have been a number of reviews of these explicit equations. However, the previous reviews are lacking insofar as they are based on differing boundary conditions and either do not consider the computational efficiency or do so by notational key strokes or statistical methods. Nor is it possible to identify easily the ranges of applicable Reynolds numbers or relative pipe roughness value that the individual equations have been optimised to calculate.

In order to identify the most accurate and computationally efficient method, a review of the major explicit friction factor equations has been carried out (Section 4.1). This established the accuracy with respect to the implicit Colebrook-White equation, the computational efficiency and the range of Reynolds numbers and relative pipe roughness values that were applicable for each equation. The determination of the accuracy and computational efficiency required a quantitative approach. The accuracy has been evaluated using a range of metrics to enable comparison of the results with those in previous reviews undertaken and cited in this research. While the metrics of mean square error and relative percentage error enable comparisons of the accuracy of the various equations to be quantified, a new qualitative approach is proposed for the identification of the applicable range of input values. This approach requires modelling the equations across the entire range of 18020 input values to produce a 3D surface model. From the model, 2D and 3D representations are produced that map the relative percentage error as the z value thereby enabling the visual identification of the applicable range of input values.

3.2.2 Improved Method of Estimating Friction Factor

Based on the review, a new equation is proposed (Section 4.2) that is computationally more efficient than previous explicit equations and achieves comparable accuracy. This is based on the premise that the explicit equation has two variables: the Reynolds number defining the flow regime, and the relative pipe roughness (which is the absolute roughness divided by the internal diameter of the pipe). Previous research (Winning, 2011) has demonstrated the value of this approach of modularising the equation for specific combinations of Reynolds numbers and relative pipe roughness in order to improve the computational efficiency. However, this approach still required a comparison to be made prior to each calculation in order to determine the appropriate constant to use for the specified variables.

For the hydraulic simulation, any change in pipe diameter or absolute pipe roughness requires a new pipe segment within the model. As can be seen (Table 3.1), the number of changes in pipeline diameter are typically few in relation to the length of the pipeline.

Pipeline	Length (km)	OD (inches)	Changes in diameter
SCPX	486	48	0
SCP	691	42	0
BTC	1768	42 & 46	1
WREP	830	21	0
SETI	550	34	0
Birmingham Airport Link	51	12	0
Finaline	233	10	0
CPMZ	280	10	0

Table 3.1 – CB&I Pipeline Projects¹⁴

The absolute roughness is usually taken as constant for the hydraulic analysis of a pipeline system based on the pipeline material. It may be reduced to simulate the use of drag reducing agents (DRA)¹⁵ that reduce the frictional pressure drop, or increased to simulate the analysis of existing pipelines where internal surface roughness increases over time.

¹⁴ *This data has been compiled from company project data.*

¹⁵ *Long-chain hydrocarbon polymers that decrease the amount of energy lost in turbulent formation. Using drag reducing agents enables pipeline operators to increase flow using the same amount of energy, or decrease the pressure drop for the same fluid flow rate.*

Given the tendency to have few, if any changes in either the line size or the absolute roughness values for a pipeline hydraulic simulation, the proposed explicit equation separates the expressions specifying the relative pipe roughness and Reynolds number. The expression containing the term for the relative pipe roughness is used as a constant in the equation, which is calculated first. The evaluation of this equation will follow the combined quantitative and qualitative approach adopted for the review of the explicit equations.

While the high-level hydraulic analysis performed within the GIS environment will be limited to steady state, the proposed equation could offer significant improvements to the more computationally intensive calculations required for transient analysis.

3.2.3 Determination of Location Class

The location class for gas pipelines is a code requirement and can be performed using a number of codes – including ASME B31.8 and IGEM/TD/1¹⁶. This component will follow a quantitative approach and the results obtained will be validated manually using a combination of GIS and CAD tools. From a qualitative perspective, this will be run on previous pipelines in order to identify whether the location class boundaries originally identified were biased in anyway.

3.3 Environmental Engineering

The SERA for the SCP and BTC pipelines for a common pipeline corridor covering 450 km in Azerbaijan and 250 km in Georgia was conducted over a three-year period from 2000 to 2003. This assessment was based on detailed site investigations in which the pipeline route was evaluated for erosion risk based on soil type, vegetation, slope and local conditions. This initial assessment was carried out by leading soil erosion experts from Cranfield University (Professors Hann and Morgan), local soil erosion experts (Dr Mirtskhoulava and Dr Nadirashvili) from the Environmental Geological Agency in Tbilisi and experienced pipeline engineers.

As part of the SERA for the SCPX project, whose route runs adjacent to the existing SCP pipeline for much of its length, a review of the erosion control methods adopted for the SCP and BTC pipelines was carried out in 2011. This was performed during three site visits in June, August and September by the author and Professor Hann. This enabled an evaluation

¹⁶ *Institution of Gas Engineers and Managers.*

of the SERA for the SCPX route when it did not run adjacent to the existing SCP pipeline. In addition, for those sections in proximity to the SCP pipeline, an assessment was made of the success of the original erosion control measures that had been put in place and used to revise the initial assessment when the soil erosion had been more severe than predicted. This constituted the SERA for the SCPX pipeline.

The SERA carried out in the field for the SCPX pipeline enables a quantitative assessment to be made of the results obtained from the model. A qualitative evaluation will be carried out through a sensitivity analysis in order to determine the impact of the soil erodability factor to slope, given the uncertainty of being able to determine accurately the soil erodability factor using remote sensed data. Various aggregated levels will also be reviewed in order to determine the most appropriate level for reporting the soil erosion risk factor.

3.4 Engineering Design

From a review of the current engineering design processes, issues of CGI and the functional design requirements, the features to be included in the AEGIS were selected. From this, a ranking of the elements identified the relative importance of the elements. In conjunction with the output of the research into the pipeline and environmental engineering, this information was used to develop the SDS for the system.

A qualitative evaluation of the engineering design component will be carried out in order to compare existing systems and a quantitative evaluation will be carried out based on performance metrics.

3.5 Design and Development of the AEGIS

The methodology for the design, development and evaluation of the AEGIS is based on the DSRM process model proposed by (Peffer et al., 2007: 58). This methodology, which is based on a problem-centred approach, identifies six stages:

1. **Identify the problem:** From a review of the current methods and process in the design of onshore pipelines (Chapter 1), a research question was proposed and refined by the initial literature survey (Chapter 2).
2. **Define the objectives:** From the literature survey, the aim and objectives of the thesis have been defined (Chapter 2).

3. **Design and development:** From the objectives identified, four key areas for further research were identified:
 - a. definition of the methodology of the thesis (Chapter 3)
 - b. pipeline hydraulic simulation within the GIS environment (Chapter 4)
 - c. estimation of the soil erosion risk from remote sensed data (Chapter 5)
 - d. automated production of deliverable documents (Chapter 6)
4. **Demonstration:** This is achieved through the development of the artefact (software) and by demonstrating the validity of the constructs, models, methods and implementation. The requirements for the software are defined in the SDS (Appendix E) and a narrative of the development of the system in Chapter 7.
5. **Evaluation:** This is achieved by evaluating the artefact, comparing it to other systems and processes currently in use, and by comparing it to the defined metrics specified in the SDS (Appendix E). This is presented in Chapter 8.
6. **Communication:** This is achieved through the publication of peer-reviewed journal papers, the presentation of conference papers (Section 2.6) and the concluding discussion in Chapter 9.

3.6 Evaluation of the AEGIS

The evaluation of the completed artefact is central to the process model adopted.

A design artefact is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve.

(Hevner et al., 2004: 85)

March and Smith argue that the research contribution of the artefact is dependent on the novelty of the constructs, models and methods rather than the application of known constructs and methods to novel tasks (1995: 260). The evaluation of the artefact needs to consider both the efficiency and effectiveness of the instantiation and its impacts on the environment and the users (ibid: 261). The methods for the evaluation of the AEGIS are selected from the design evaluation methods presented by Hevner et al. in Table 3.2.

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Table 3.2 – Design Evaluation Methods

(Hevner et al., 2004: 86)

There is general agreement in the literature about the validity of the approach to design science evaluation proposed by (Hevner et al., 2004). Equally, there appears to be an absence of clarity in the application of evaluation in the field of design science:

However, they¹⁷ do not provide much guidance in choosing among extant evaluation methods.

(Pries-Heje et al., 2008: 4)

Notwithstanding the consensus that evaluation is essential, there is little guidance about what is desirable, acceptable or customary in evaluation.

(Peppers et al., 2012: 398)

This lack of guidance in the selection of appropriate evaluation methods, with reference to the methods proposed by Hevner et al. is addressed partially by (Dresch et al., 2014: 98-99). Because of this, the scope of the evaluation methods and the rationale for the selection of the evaluation methods for the AEGIS is discussed under these five headings. The evaluation methods outlined in Table 3.2 fall into five main categories, which are discussed with respect to their applicability to the evaluation of the AEGIS in Chapter 8.

¹⁷ Hevner et al., 2004.

Chapter 4

PIPELINE ENGINEERING

This chapter is divided into three sections. The first section (**Research Objective 2a**) covers the review of explicit equations for the estimation of the friction factor in single-phase Newtonian pipelines. This is in part based on research initially undertaken as part of the project for a BEng (Hons) in Mechanical Engineering Design (Winning, 2009). As part of this research, a review of the existing explicit friction factor equations was conducted. This review has been significantly changed through the inclusion of a number of more recent equations, the methods of analysis, and the use of 2D and 3D contour plots to indicate the range of accuracy for each equation. The outcome of this subsequent research was published in the peer-reviewed journal *Flow, Turbulence and Combustion* (Winning and Coole, 2013).

The second section (**Research Objective 2b**) proposes an improved computational method for the estimation of friction factor in pipelines. This is based on earlier research undertaken as part of the project for a MEng (Hons) in Mechanical Engineering Design (Winning, 2011). In the earlier work, a polychotomous method was proposed in which the range of relative pipe roughness and Reynolds numbers were divided into four sub-ranges. The new method presented, yields further computational efficiencies by only sub-dividing the ranges by the relative pipe roughness and keeping the Reynolds number as the only variable in the equation. This research has been published in the peer-reviewed journal *International Journal of Numerical Methods for Heat and Fluid Flow* (Winning and Coole, 2015).

The final section (**Research Objective 2c**) presents a method for the determination of the location class for gas pipelines according to international standards, and demonstrates the applicability of GIS to solving geospatial engineering problems. This approach was presented at the ESRI European Petroleum User Group Conference (Winning, 2014a).

4.1 Review of Explicit Friction Factor Equations

The aim of this section is to provide a consistent review of the available explicit equations across a wide range of Reynolds numbers and relative pipe roughness values, thus identifying the absolute and relative accuracy to the implicit Colebrook-White equation, the applicable range, and the relative computational efficiency for each explicit equation. The equations reviewed, summary tables of results and contour plots are included in Appendices A1, A2 and A3 respectively.

4.1.1 Supplementary Literature Review

Pressure loss in a pipeline is calculated using the Darcy-Weisbach equation, which requires the friction factor to be known – the friction factor being dependent on both the relative roughness (absolute roughness divided by the internal diameter) of the internal wall of the pipe and the Reynolds number, which defines the flow regime. The pipe is considered to be smooth when the projections of the surface are completely submerged in the viscous laminar layer (Farshad et al., 2001: 148) ; and the thickness of the viscous laminar layer is dependent on fluid properties. Therefore, the effect of the absolute pipe roughness on the fluid is dependent on the magnitude of the Reynolds number.

Due to its applicability over a wide range of Reynolds numbers and relative pipe roughness values, the Colebrook-White equation (Colebrook, 1939, Colebrook and White, 1937) has become the accepted standard for calculating the friction factor in pipes. This equation is a development of the Prandtl (Prandtl, 1952) smooth pipe equation and the von Karman (Von Karman, 1934) rough pipe equation. The Colebrook-White equation is customarily given as

$$\frac{1}{\sqrt{f_f}} = -4 \log \left(\frac{\varepsilon}{3.7D} + \frac{1.256}{\text{Re} \sqrt{f_f}} \right) \quad (\text{Eq. 4.1})$$

where

- f_f = Fanning friction factor (dimensionless)
- ε = Absolute Pipe Roughness (mm)
- D = Pipe internal diameter (mm)
- Re = Reynolds number (dimensionless)

Equation 4.1 Colebrook-White Equation (Perry and Green, 1997: 6-11)

However, the Colebrook-White equation is implicit with respect to the friction factor and therefore requires an iterative solution – for example, the Newton-Raphson method. Where numerous calculations are required, the use of iterative calculations will have a significant impact on the time taken to obtain a solution, even for fast computer-based systems. To address this issue, a number of explicit equations for the estimation of the friction factor have been developed since the first explicit relationship was proposed in 1947 (Moody, 1947). These equations have increased in accuracy but at the cost of increased complexity.

There have been a number of comparative reviews of explicit equations, usually in support of a new explicit equation. The equations reviewed in the comparative studies discussed are identified in Appendix A1.

The first of these reviews was carried out in April 1985 (Gregory and Fogarasi, 1985). The impact of this review on subsequent research is evident from the books (Gao et al., 2006, Takács, 2004) and papers (Özger and Yildirim, 2009, Schroeder Jr, 2010, Sonnad and Goudar, 2006, Sonnad and Goudar, 2004, Yildirim, 2009) citing their work, which frequently use the conclusions of the Gregory and Fogarasi review as a starting point for new work. The review compared the accuracy of twelve explicit friction factor equations to results obtained using the Colebrook-White equation. For each equation, Reynolds numbers in the range 4×10^3 to 10^8 and relative pipe roughness values of 10^8 to 5×10^{-2} were used. Six Reynolds numbers and eight relative pipe roughness values were used, thereby generating 48 data points for each equation. In this review, the explicit equations were stated as being in terms of the Fanning friction factor. During the course of this research, it was found that Equation A1.3 (Wood, 1966), Equation A1.16 (Serghides, 1984 - Eq. 2) and Equation A1.17 (Serghides, 1984 - Eq. 3) were returning the Darcy friction factor rather than the Fanning friction factor as claimed, this being confirmed by reference to the original sources. The Fanning friction factor is based on the hydraulic radius whereas the Darcy friction factor is based on the hydraulic diameter; Darcy friction factor values are therefore four times those of the Fanning friction factor. Because of this error, the conclusion of Gregory and Fogarasi that Equation A1.9 (Chen, 1979) represented the last real improvement is questionable. Whereas Equation A1.9 (Chen, 1979) represented an improvement in accuracy over Equation A1.1 (Moody, 1947) by an order of magnitude of five, Equation A1.16 (Serghides, 1984 - Eq. 2) represented an improvement in accuracy over Equation A1.1 (Moody, 1947) by an order of magnitude of seven.

A second comparative review was carried out (Zigrang and Sylvester, 1985) using the same boundary conditions as (Serghides, 1984) – namely a matrix of 70 values from ten relative pipe roughness values ranging from 4×10^{-5} to 5×10^{-2} and a range of seven Reynolds values from 2500 to 10^8 . This study was very similar to that of the (Gregory and Fogarasi, 1985) review with respect to the explicit equations reviewed, with the exception of excluding Equation A1.3 (Wood, 1966) and including the equation by (Chen, 1984). This equation (Chen, 1984) is not reviewed in the current research because the author stated that it was a simplified equation and not expected to be of high accuracy – which was confirmed by preliminary analysis. The recommendations were similar to those of (Gregory and Fogarasi, 1985), with Equation A1.9 (Chen, 1979) being recommended as the simplest of the most accurate equations, while Equation A1.16 (Serghides, 1984 - Eq. 2) was identified as the most accurate overall. In addition, this study compared the equations complexity – as defined by the number of algebraic notation calculator key strokes required to solve the equation for $Re=10^3$ and $\varepsilon/D = 0.001$.

Two further reviews were conducted in 2007 and 2008 (Goudar and Sonnad, 2007, Goudar and Sonnad, 2008). Both of these reviews only assessed the accuracy of the equations, with the only new equations reviewed being Equation A1.19 (Manadilli, 1997) in the 2007 review and Equation A1.20 (Romeo et al., 2002) in the 2008 review. Both of these studies were conducted using 20 relative pipe roughness values, ranging from 10^{-6} to 5×10^{-2} and 500 values of Reynolds numbers ranging from 4×10^3 to 10^8 , producing a matrix of 10000 points. This represents a significant increase in the size of the matrix of values reviewed compared to the previous two studies. In the study (Goudar and Sonnad, 2008), the conclusion was that the Equation A1.16 (Serghides, 1984 - Eq. 2) was the most accurate of those equations reviewed. Equation A1.16 (Serghides, 1984 - Eq. 2) was not reviewed in the 2007 study.

In 2009, there was a further study (Yildirim, 2009) based on the same matrix of values used by (Goudar and Sonnad, 2008). Yildirim does not make any definitive recommendations but concludes the study by summarising the data previously presented in tabulated form, and highlighting that the three most accurate equations are Equation A1.9 (Chen, 1979), Equation A1.21 (Sonnad and Goudar, 2006) and Equation A1.20 (Romeo et al., 2002). Unfortunately, neither Equation A1.16 (Serghides, 1984 - Eq. 2) nor Equation A1.17 (Serghides, 1984 - Eq. 3) was reviewed in this study.

In 2011, (Brkić, 2011) performed a review of 20 equations using 20 relative pipe roughness values ranging from 10^{-6} to 7.5×10^{-2} and 37 values of Reynolds numbers ranging from 10^4 to 10^8 , producing a matrix of 740 points. In addition to determining the accuracy, this study used the same method for estimating the complexity of the equation as used twenty-six years earlier by (Zigrang and Sylvester, 1985). This review introduced the equations Equation A1.5 (Eck, 1954), Equation A1.22 (Rao and Kumar, 2006), Equation A1.23 (Buzzelli, 2008), Equation A1.24 (Avci and Karagoz, 2009) and Equation A1.25 (Papaevangelou et al., 2010). This review did not offer any definite conclusions other than that the equations were all very accurate with the exception of Equation A1.10 (Round, 1980), Equation A1.5 (Eck, 1954), Equation A1.1 (Moody, 1947), Equation A1.3 (Wood, 1966) and Equation A1.22 (Rao and Kumar, 2006).

In 2011 another review of 16 equations was conducted (Genić et al., 2011) and performed over the same range of values as (Goudar and Sonnad, 2008) and (Yildirim, 2009) with a very large matrix of 1 million points. This review introduced Equation A1.2 Altshul 1952, cited in (Genić et al., 2011), Equation A1.18 (Tsal, 1989), Equation A1.28 (Fang et al., 2011), Equation A1.26 (Brkić, 2011 - Eq. A) and Equation A1.27 (Brkić, 2011 - Eq. B). This review, like the work of (Romeo et al., 2002), used a Model Selection Criterion and the Akaike Information Criterion (AIC)¹⁸ to perform a statistical comparison of the relative computational efficiency. This review concluded with the recommendation to use Equation A1.14 (Zigrang and Sylvester, 1982 - Eq. 12).

4.1.2 Analysis

The explicit equations (Appendix A1) were all coded as Visual Basic functions in a Microsoft Excel spreadsheet. The equations were coded in terms of the friction factor (either Darcy or Fanning) as stipulated in the cited equation. To ensure a uniform output for the equations, where the friction factor was returned as a Fanning friction factor, the result of the calculation was multiplied by four. Therefore, all the friction factor functions return the Darcy friction factor. A range of Reynolds numbers and relative pipe roughness values were selected to encompass the limits of the previous comparative studies reviewed. A range of 901 Reynolds numbers was selected for the review between $Re \geq 4 \times 10^3$ and $\leq 4 \times 10^8$ and 20 relative pipe roughness values were selected between $\varepsilon/D \geq 10^{-6}$ and $\leq 10^{-1}$, thus producing a matrix of 18020 points for each calculation. The dimensions of the matrix were

¹⁸ *Akaike Information Criterion, a measure of the fit of a statistical model to data used to determine the accuracy and complexity of the model.*

chosen to ensure that any local variations were identified and that sufficient data were collected to generate smooth contour plots.

4.1.2.1 Accuracy to the Implicit Colebrook-White Equation

For each of the explicit equations, the minimum, maximum and mean absolute error (Equation 4.2) from the Colebrook-White equation was calculated across the range of Reynolds numbers and relative pipe roughness values studied. In addition, the minimum, maximum and mean relative percentage error (Equation 4.3) was calculated and finally the MSE (Equation 4.4) was determined. The Colebrook-White values were determined to an accuracy of 10^{-9} for comparative purposes. The results are in Table A2.1 (Appendix A2), ordered by the mean relative percentage error.

$$\text{Absolute error} = |f_{true} - f_{estimated}| \quad (\text{Eq. 4.2})$$

Equation 4.2 Absolute Error

$$\text{Relative error} = \left[\frac{f_{true} - f_{estimated}}{f_{true}} \right] \times 100 \quad (\text{Eq. 4.3})$$

Equation 4.3 Mean Relative Percentage Error

$$\text{MSE} = \frac{\sum_{i=1}^{i=N} (f_{true} - f_{estimated})^2}{N} \quad (\text{Eq. 4.4})$$

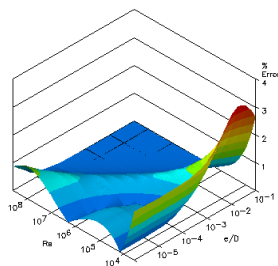
Equation 4.4 Mean Square Error

The explicit equations were also reviewed and sorted according to the MSE. In addition, an adjectival grade was given to each of the explicit equations according to the size of the MSE (Table A2.2 – Appendix A2):

- large: $\text{MSE} \geq 5 \times 10^{-6}$
- medium: $\text{MSE} \geq 10^{-8} < 5 \times 10^{-6}$
- small: $\text{MSE} \geq 10^{-11} < 10^{-8}$
- very small: $\text{MSE} < 10^{-11}$

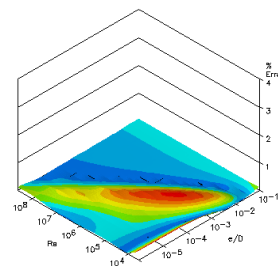
Contour plots were produced (Appendix A3) which mapped the relative percentage error (z value) to the log of the relative pipe roughness (x-axis) and the log of the Reynolds number (y-axis). A description of the error distribution was defined as follows:

- **Upper Diagonal:** For equations where the magnitude of the MSE is medium or small and the lowest errors are mainly confined to the upper diagonal (higher Reynolds numbers and rougher pipe) – these equations exhibit the greatest error in the transitional zone, where Reynolds numbers are low and the relative roughness is high.
- **Diagonal Ridge Error:** Where the magnitude of the MSE is medium or small and the distribution of the highest errors is generally confined to the diagonal line, from high Reynolds numbers to rough pipe.
- **Diagonal Ridge:** Where the magnitude of the MSE is small and the distribution of the lowest errors is generally confined to the diagonal line, bisecting the values – this is the inverse of the Diagonal Ridge Error.
- **Unclassified:** For cases that do not exhibit a discernible error distribution pattern.



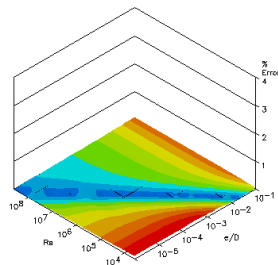
Upper Diagonal

Equation A1.4 (Churchill, 1973)



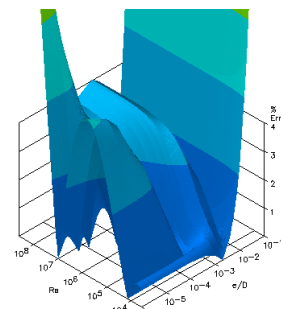
Diagonal Ridge Error

Equation A1.9 (Chen, 1979)



Diagonal Ridge

Equation A1.20 (Romeo et al., 2002)



Unclassified

Equation A1.1 (Moody, 1947)

Figure 4.1 – Error Distribution Classification

These different error distributions are identified in Figure 4.1 for Equation A1.4 (Churchill, 1973), Equation A1.9 (Chen, 1979), Equation A1.20 (Romeo et al., 2002) and Equation A1.1 (Moody, 1947) respectively. The magnitude of the error increases from dark blue through green, yellow and orange to red, though the absolute values for the colour banding are dependent on the magnitude of the MSE and therefore vary for each equation. It should be noted that the vertical scale for all the contour plots is the same to allow direct comparisons to be made.

The previous studies have reported the accuracy of the explicit equations using a variety of methods:

- relative percentage error – Gregory & Fogarasi (Gregory and Fogarasi, 1985), Zigrang & Sylvester (Zigrang and Sylvester, 1985) and Brkić (Brkić, 2011)
- absolute error - Goudar & Sonnad (Goudar and Sonnad, 2007, Goudar and Sonnad, 2008)
- relative percentage error and MSE - Genić (Genić et al., 2011)
- relative percentage error, absolute error and MSE - Yildirim (Yildirim, 2009)

While the MSE provides a good indication of the overall accuracy of the explicit equation, spikes within the data only become apparent with the maximum percentage error. As can be seen from the contour plots, some of the explicit equations have very high errors over a small range of input values thus producing spikes, which while immediately obvious on the plots might not be so readily identified in the tables and certainly cannot be identified if both the MSE and maximum relative percentage errors are not reported.

However, neither of these methods satisfactorily indicates the range of applicable Reynolds numbers and relative pipe roughness values that produce an acceptable accuracy for a given explicit equation. Using a combination of 2D and 3D contour plots, the applicable range is easily identified, even for the large matrix of values being examined.

4.1.2.2 Computational Efficiency

Although the previous reviews, which considered the complexity or efficiency for the explicit equations, did so either by reference to the number of algebraic notation calculator key strokes or by statistical modelling, this study determined the relative computational efficiency for the explicit equations by comparing the time taken to perform the equations. It

is believed that this provides a more practical method of determining the relative computational efficiency.

The 100 million friction factor calculations were performed using randomly generated values for the Reynolds number and the relative pipe roughness values between the limits specified in this research, for each of the explicit equations. The total time taken to perform the calculations was recorded and the relative computational efficiency determined by dividing the time taken for the explicit equation to perform the calculations by the time taken by the implicit Colebrook-White equation. This was performed three times and the mean values for the relative computational efficiency were calculated and ranked. These results are shown in Table A2.3 (Appendix A2).

4.1.2.3 Comparative Analysis

The explicit equations were ranked according to both the MSE (Rank A) and the computational efficiency (Rank B). These rankings were then combined to produce an overall ranking (Rank C). In order to produce a final ordinal ranking, the raw combined rank was then ranked according to Rank A, as shown in Table A2.4 – Appendix A2.

As expected, those equations with the greater number of internal iterations were generally more accurate and required a greater computational effort. While the accuracy ranged from 1.75×10^{-4} to 5.62×10^{-12} , the relative computational efficiency only ranged from 0.488 to 0.716. These results are shown in Table A2.4 – Appendix A2.

4.1.3 Results

From Table A2.1 and Table A2.2 (Appendix A2), it can be seen that the accuracy ranking changes slightly depending on whether the equations are ordered by MSE or by the mean relative percentage error. The most significant changes were for Equation A1.8 (Churchill, 1977), Equation A1.26 (Brkić, 2011 - Eq. A) and Equation A1.22 (Rao and Kumar, 2006), though generally the variations were small. This research found that Equation A1.23 (Buzzelli, 2008) is the most accurate overall, with an MSE of 5.62×10^{-12} , and the second most accurate is Equation A1.16 (Serghides, 1984 - Eq. 2) with an MSE of 7.51×10^{-12} .

The relative computational efficiency (as shown in Table A2.3 – Appendix A2) demonstrates the general correlation between accuracy and computational efficiency. Ignoring those equations with large magnitudes of error as shown in Table A2.2 (Appendix A2), the most

computationally efficient equations were Equation A1.5 (Eck, 1954), Equation A1.4 (Churchill, 1973) and Equation A1.7 (Swamee and Jain, 1976) – which all produced medium magnitudes of error. The equations with a small magnitude of error and most computationally efficient were Equation A1.11 (Shacham, 1980), Equation A1.13 (Zigrang and Sylvester, 1982 - Eq. 11) and Equation A1.28 (Fang et al., 2011). In the case of the two most accurate equations – Equation A1.16 (Serghides, 1984 - Eq. 2) and Equation A1.23 (Buzzelli, 2008) – the variation in ranking of computational efficiency was not significant, these equations being ranked 20th and 27th respectively.

Table A2.4 (Appendix A2) combines the performance of the equations based on accuracy and computational efficiency. The explicit equations with the lowest combined ranking were Equation A1.21 (Sonnad and Goudar, 2006), Equation A1.17 (Serghides, 1984 - Eq. 3) and Equation A1.16 (Serghides, 1984 - Eq. 2) – these having decreasing magnitudes of error of medium, small and very small respectively.

As 12 of the equations reviewed did not have stated applicable ranges, this study has applied the same conditions to all the equations. While this obviously affects the accuracy of the results claimed by the authors where an applicable range was stated, it has been done in order to compare the equations reviewed; however, by reference to the 2D and 3D contour plots, the range of applicability for each equation is clear. It should be noted that Equation A1.22 (Rao and Kumar, 2006) was developed to satisfy experimental data and not to approximate the implicit Colebrook-White equation. It is arguable therefore whether it should have been reviewed as a general explicit equation (Brkić, 2011) as it only serves to show the variation between the experimental data and the implicit Colebrook-White equation.

4.1.4 Discussion

This research has identified the most accurate explicit equations for approximating the values obtained by the implicit Colebrook-White equation, and has determined the relative computational efficiency for each explicit equation. By the innovative use of 2D and 3D contour modelling over an extensive range of values, this study has also identified the applicable range for each explicit equation in a way that enables the reader to assimilate quickly the information from the vast number of underlying calculations.

Any explicit equation can only approximate the value obtained by the implicit Colebrook-White equation. Therefore, the value of an explicit equation in approximating the implicit

Colebrook-White equation is a function of both accuracy and computational efficiency and a review of one without the other is of questionable value. As can be seen from Table A2.4 (Appendix A2), the most appropriate equations are not necessarily the ones with greatest accuracy; rather they are the ones that are of a higher order of accuracy while being more efficient.

By referring to the tables and contour plots within this study, it is possible to select the explicit equation that best meets the criteria of required accuracy, relative pipe roughness, predicted flow regime, and number of calculations to be performed – taking into account the inherent uncertainty in estimating some of the input parameters.

4.2 Improved Method of Estimating Friction Factor

From the previous study, which reviewed explicit approximations of the implicit Colebrook-White equation, it was felt that an improved computational method should be investigated. The majority of pipeline hydraulic simulations are based on systems with a constant absolute pipe roughness, with few changes if any to the pipe diameter with respect to the length of the pipeline system. Therefore, the relative pipe roughness is constant for the entire system, or for significant sections within the system. Because of this, it was proposed to investigate the approximation of the friction factor using a simplified equation and by modifying the constants to satisfy specific ranges of relative pipe roughness values in an attempt to produce an explicit approximation with improved computational efficiency for a comparable level of accuracy.

4.2.1 Approach

Prior to undertaking the investigation, the relative computational effort for the mathematical operations encountered in the explicit equations was determined by performing 100 million calculations for each mathematical operation, each repeated five times. The average computational time was recorded and compared to the fastest operation (addition) to determine a relative computational effort for each mathematical operation. As can be seen in the tabulated results (Table 4.1), the relative computational effort varied significantly.

Operation	Duration (Seconds) for 100 Million Calculations					Average	Relative Effort
	Run 1	Run 2	Run 3	Run 4	Run 5		
Addition	23.2	23.2	24.2	23.2	23.2	23.40	1.00
Subtraction	27.3	27.3	27.3	27.3	28.3	27.50	1.18
Division	32.3	31.3	32.3	31.3	31.3	31.70	1.35
Multiplication	35.4	36.4	35.4	36.4	37.4	36.20	1.55
Squared	50.5	51.5	51.5	51.5	50.5	51.10	2.18
Square Root	53.5	53.5	53.5	53.5	54.5	53.70	2.29
Cubed	55.6	54.5	55.6	55.6	56.6	55.58	2.38
Ln	63.0	63.0	63.0	63.0	63.0	63.00	2.69
Cubed Root	64.0	64.0	63.0	63.0	63.0	63.40	2.71
Fractional Exp	77.2	77.2	78.2	78.2	77.2	77.60	3.32
Log	78.2	79.2	79.2	79.2	78.2	78.80	3.37

Table 4.1 – Relative Computational Efficiency by Operation

Romeo et al. proposed a simplified equation – Equation 4.5 Generalised Equation (Romeo et al., 2002 - Eq. 2) – which is a representation of Equation A1.4 (Churchill, 1973), Equation A1.7 (Swamee and Jain, 1976), Equation A1.10 (Round, 1980) and Equation A1.15 (Haaland, 1983).

$$\frac{1}{\sqrt{f_d}} = \left\{ -a_0 \log \left[\left(\frac{a_1}{a_2 + \text{Re}} \right)^{n_1} + \left(\frac{\varepsilon / D}{a_3} \right)^{n_2} \right] \right\}^m \quad (\text{Eq. 4.5})$$

where

- f_d = Darcy or D’arcy-Weisbach friction factor (dimensionless)
- ε = Absolute Pipe Roughness (mm)
- D = Pipe internal diameter (mm)
- Re = Reynolds number (dimensionless)

Equation 4.5 Generalised Equation (Romeo et al., 2002 - Eq. 2)

Based on the results of determining the computational effort for the various mathematical operations, the exponents’ n_1 , n_2 and m were initially set to unity given the high relative effort of the mathematical operation. The preference given to modification of the variables was in order of increasing relative effort, the exception being the modification of the variable n_2 , given that the relative pipe roughness would be constant for the system and this expression would therefore only need to be calculated once for each pipe diameter.

The range of the Reynolds numbers and relative pipe roughness values used in this study is identical to those used in the previous study – namely a range of 901 Reynolds numbers

between $Re \geq 4 \times 10^3$ and $\leq 4 \times 10^8$ and 20 relative pipe roughness values between $\epsilon/D \geq 10^{-6}$ and 10^{-1} . The complete range of relative pipe roughness values was sub-divided into 10 ranges, and using multivariate non-linear regression, the optimum values for the constants were determined for each range of relative roughness values. The results ordered by relative percentage error (Table B1.1) and by the MSE (Table B1.2) are included in Appendix B1. The values obtained for the constants are presented in Table 4.2.

Relative Roughness		Constants						
Min	Max	a_0	a_1	a_2	a_3	n_1	n_2	m
6.0E-02	1.0E-01	1.8	6.2	100	3.73	1	1.109	1
2.0E-02	6.0E-02	1.8	6.7	130	3.73	1	1.109	1
8.0E-03	2.0E-02	1.8	7.1	160	3.73	1	1.109	1
4.0E-03	8.0E-03	1.8	7.2	180	3.73	1	1.109	1
1.0E-03	4.0E-03	1.8	7.32	300	3.73	1	1.109	1
6.0E-04	1.0E-03	1.8	7.5	520	3.73	1	1.109	1
2.0E-04	6.0E-04	1.8	7.41	490	3.73	1	1.109	1
5.0E-05	2.0E-04	1.8	7.35	480	3.73	1	1.109	1
5.0E-06	5.0E-05	1.8	7.2	370	3.73	1	1.109	1
1.0E-06	5.0E-06	1.8	7.2	380	3.73	1	1.109	1

Table 4.2 – Determination of Constants for Equation 4.5

As can be seen, the values for a_0 , a_1 , n_1 and the relative pipe roughness ϵ / D were all constant and the indices n_2 and m were one, so the equation was further simplified.

$$f_d = \left\{ -1.8 \log \left[\left(\frac{a_1}{a_2 + Re} \right) + P_1 \right] \right\}^{-2} \tag{Eq. 4.6}$$

where P_1 is defined as:

$$P_1 = \left(\frac{\epsilon/D}{3.73} \right)^{1.109}$$

and

- f_d = Darcy or D’arcy-Weisbach friction factor (dimensionless)
- ϵ = Absolute Pipe Roughness (mm)
- D = Pipe internal diameter (mm)
- Re = Reynolds number (dimensionless)

Equation 4.6 Simplified Equation (Winning and Coole, 2015 - Eq. 3)

For each range of relative pipe roughness values, P_1 is first obtained and then used in Equation 4.6 with the appropriate constants for a_1 and a_2 given in Table 4.3. By calculating the value for P_1 once, further computational efficiency is obtained.

Relative Roughness		Constants	
Min	Max	a_1	a_2
6.0E-02	1.0E-01	6.2	100
2.0E-02	6.0E-02	6.7	130
8.0E-03	2.0E-02	7.1	160
4.0E-03	8.0E-03	7.2	180
1.0E-03	4.0E-03	7.32	300
6.0E-04	1.0E-03	7.5	520
2.0E-04	6.0E-04	7.41	490
5.0E-05	2.0E-04	7.35	480
5.0E-06	5.0E-05	7.2	370
1.0E-06	5.0E-06	7.2	380

Table 4.3 – Determination of Constants for Equation 4.6

4.2.2 Analysis

In the previous study, 28 explicit equations were assessed for accuracy and computational efficiency compared to the Colebrook-White equation and assigned a rank according to the combined result. Using the same parameters, a range of 901 Reynolds numbers was selected for the review between $Re \geq 4 \times 10^3$ and $\leq 4 \times 10^8$, and 20 relative pipe roughness values were selected between $\varepsilon/D \geq 10^{-6}$ and $\leq 10^{-1}$, thus producing a matrix of 18020 points for each calculation. It should be noted that irrespective of the friction factor specified in the explicit equation, the results are all converted to the Darcy friction factor for comparison purposes. To make a comparison to the previous study possible, Table B1.1 to B1.4 (Appendix B1) are produced in the same format as Table A2.1 to A2.4 (Appendix A2) from the previous study, with the addition of Equation 4.6.

For each of the explicit equations, the minimum, maximum and mean absolute error from the Colebrook-White equation was calculated across the range of Reynolds numbers and relative pipe roughness values studied. In addition, the minimum, maximum and mean relative percentage error was calculated; and finally, MSE was determined. The Colebrook-White values were determined to an accuracy of 10^{-9} for comparison purposes; these results are tabulated in Table B1.4 (Appendix B1), with the error distribution classified as previously shown in Figure 4.1 and given in Table B1.2 (Appendix B1). The computational efficiency was calculated using the method used previously and is shown in Table B1.3 (Appendix B1).

The explicit equations were ranked according to both the MSE (Rank A1) and the computational efficiency (Rank B). These rankings were then combined to produce an

overall ranking (Rank C1). In order to produce a final ordinal ranking, the raw combined rank was then ordered according to Rank A1, as shown in Table B1.4 (Appendix B1).

Due to the method employed the error distribution of Equation 4.6 exhibits stratification within the error distribution (Figure 4.2).

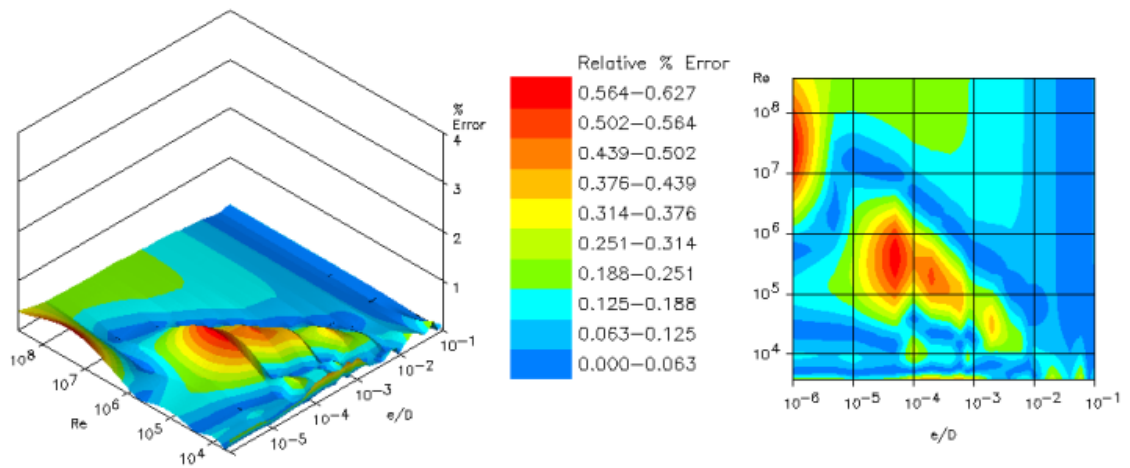


Figure 4.2 – Error Distribution for Equation 4.6

4.2.3 Results

It should be noted that the values for the constants in Equation 4.6 have been determined to minimise the MSE of the equation rather than the relative percentage error. However, if the results in Table B1.4 (Appendix B1) are re-ordered by combining the mean relative percentage error and computational efficiency, there is a slight change in the ranking. Importantly, however, there is no difference in the ranking of the first three equations – Equation 4.6, Equation A1.21 (Sonnad and Goudar, 2006) and Equation A1.17 (Serghides, 1984 - Eq. 3) – as can be seen from Table B1.5 (Appendix B1).

As can be seen from Table B1.4 and Table B1.5 (Appendix B1), the proposed equation and method offers an improvement in computational efficiency without compromising accuracy, while its simplicity reduces the likelihood of errors in coding the equation. Figure 4.3 and Figure 4.4 show the equations plotted against the computational efficiency and MSE rankings. In Figure 4.3, the equation numbers are placed next to the corresponding point, while Figure 4.4 shows the same plot with the combined ranking next to the point. In both figures, the equations shown in blue (fourth quadrant) are more accurate but less computationally efficient than the new equation (shown in red); the equations in green

(second quadrant) are computationally more efficient but less accurate; and the equations in grey (first quadrant) are both less efficient and less accurate.

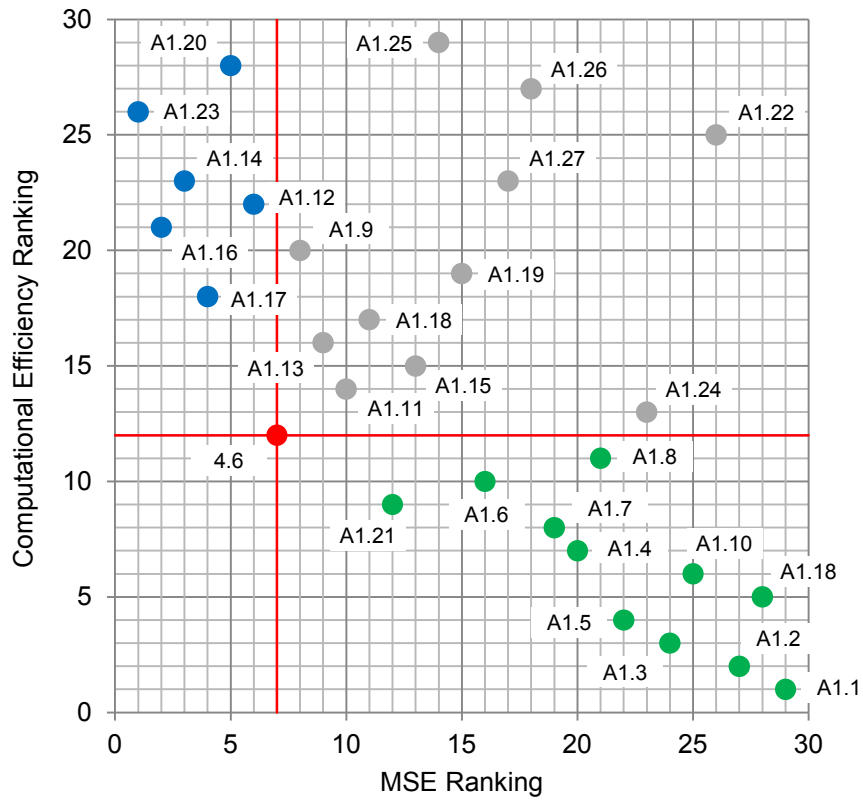


Figure 4.3 – Ranking Plot (Showing Equation Numbers)

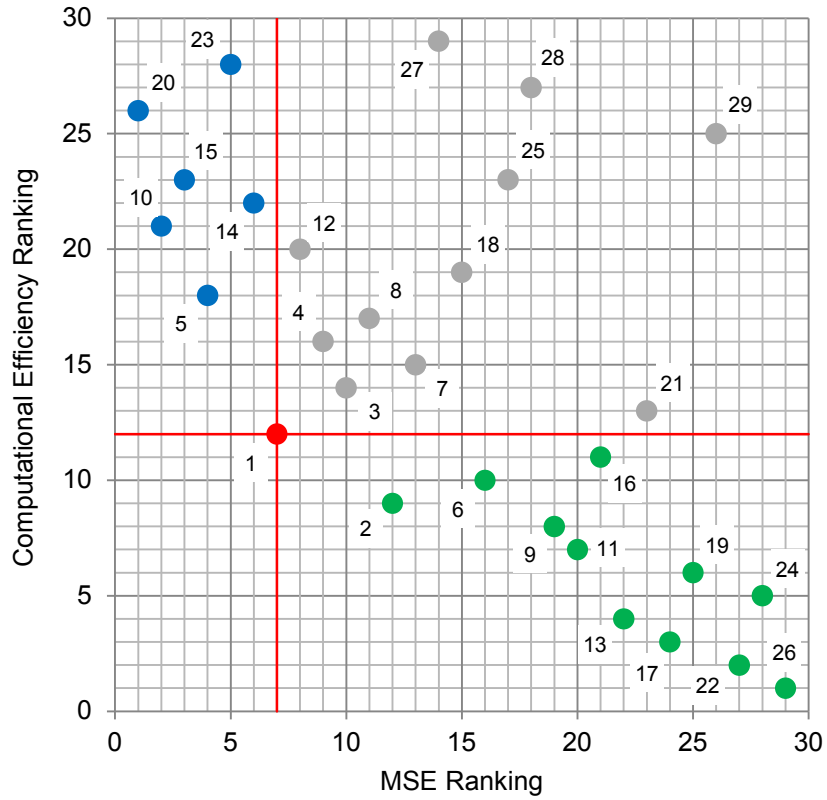


Figure 4.4 – Ranking Plot (Showing Combined Rank)

Although Figure 4.3 and Figure 4.4 are useful to visualise the spread of the equations with respect to both the computational efficiency and the accuracy, the plot based on the normalised values for computational efficiency and MSE accuracy shows the true spread of the equations (Figure 4.5), with the same colour coding as the preceding two figures.

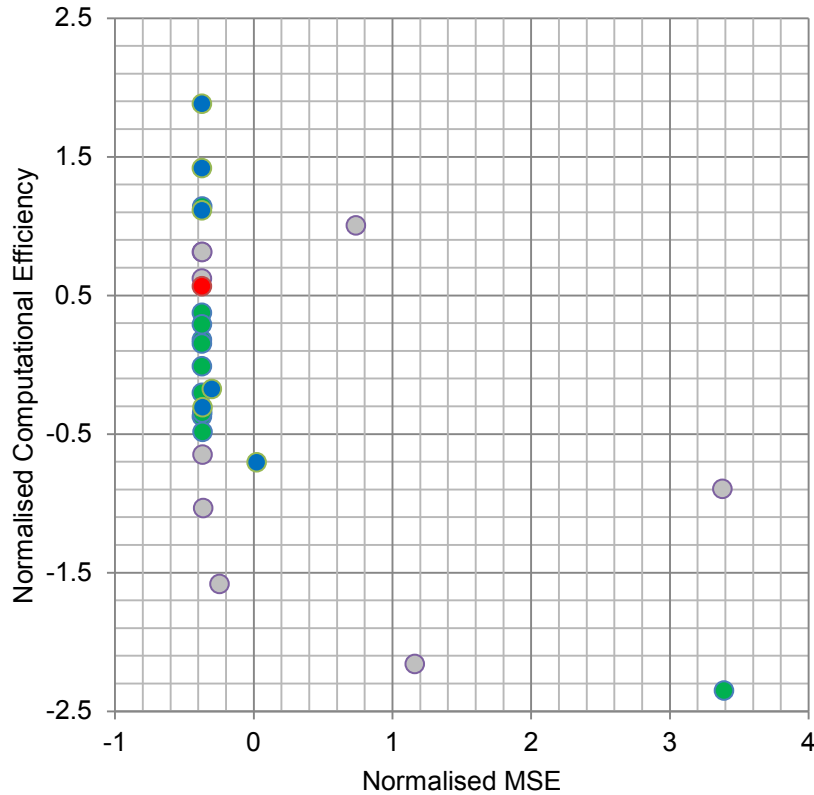


Figure 4.5 – Normalised Plot for Accuracy and Computational Efficiency

4.2.4 Discussion

The development of explicit equations to estimate the friction factor in pipes as determined by the implicit Colebrook-White equation is only beneficial if the loss in accuracy is not significant, whilst measurably improving the computational efficiency. Given the inherent uncertainty in determining the absolute pipe roughness, the value of excessive accuracy is questionable, particularly if it reduces the computational efficiency of the explicit equation. Due to the complex relationship between flow regime and pipe roughness, there is a limit to the scope for further computational efficiency through simplification of the equation; therefore, engineers must look to the computational methods used to perform these calculations in order to achieve further improvements in efficiency.

As the majority of pipeline systems are modelled with few or no changes in pipe diameter and, typically, a constant absolute pipe roughness, the approach outlined in this paper has the potential to offer significant improvements in the computational efficiency of determining the friction factor in the majority of pipeline hydraulic simulations.

By subdividing the applicable relative roughness values into ten ranges, it has been possible to produce a simplified equation with three constants, with the only remaining variable being the Reynolds number. Although the number of ranges of relative roughness values could be increased leading to potentially greater accuracy, the method outlined is able to determine the friction factor with sufficient practical accuracy. This simplified equation not only offers a significant improvement in computational efficiency given its accuracy, but it is also easier to code, enabling engineers to calculate the frictional pressure loss for pipes using a simpler equation.

4.3 Determination of Location Class

For gas transmission pipelines, the design factor is in part defined by code requirements according to the population density within the proximity of the pipeline. This determines the minimum wall thickness at any given location along the pipeline. While the wall thickness may be increased due to engineering constraints, it cannot be reduced below the minimum proximity code requirements. There are a number of different codes and these identify the design factor requirements in different ways. The IGE/TD/1 is the standard usually adopted for all UK gas transmission lines and the ASME B31.8 is the code applied in the United States. Apart from its relevance in the United States, the latter code is frequently used in other parts of the world including the Middle East, the former Soviet Union and Africa. The method proposed is based on the ASME B31.8 code given its wider acceptance. However, the choice of code is largely immaterial in demonstrating the application of GIS techniques to calculating geospatial engineering code requirements.

An extract of the ASME B31.8-2012 standard covering the relevant sections for the determination of the location class based on proximity of human habitation is attached for reference in Appendix C1.

4.3.1 Supplementary Literature Review

Although the failure rate of gas pipelines is low, the consequences of failure are potentially very serious. The risk associated with the failure of gas pipelines is the mathematical product of the probability and the consequences of the event. Mitigating the risk may therefore be achieved through reducing the likelihood of failure, reducing the consequences of failure, or some combination of the two (ASME, 2012b: 8).

Increasing demand for energy coupled with advances in material technology and construction techniques has significantly increased the pressure and diameter of gas pipelines over the last 40 years (EGIG, 2011: 17), thereby rendering the consequences of pipeline failure more serious. However, the probability of failure has decreased over a similar period, as shown in Table 4.4.

Region	Period	Exposure (km-year)	Failure Frequency (1,000 km-year)		Source
			Historic	5 Year Average	
Europe	1970-2010	3.55x10 ⁶	0.35	0.16	EGIG ¹⁹
Canada	2000-2008	1.91x10 ⁵	0.10	NA	NEB
UK	1962-2010	7.73x10 ⁵	0.23	0.093	UKOPA
USA	1985-1997	5.96x10 ⁶	0.11	NA	DOT-PRCI

*Table 4.4 – Frequency of Failure for Gas Pipelines
(Cunha, 2012: 524)*

Given the inherent growth in the seriousness of the consequences of pipeline failure, mitigation of the probability of failure is fundamental to PIM; and understanding the reasons why gas pipelines fail is central to this. In 1982 six European gas transmission operators set up EGIG¹⁹. It now comprises 15 operators collecting incident data for over 135000 km of pipeline per annum with a total exposure, expressed as the pipeline length multiplied by the period of operation, of 3.55 million km-year (EGIG, 2011: 6). Figure 4.6 shows the distribution of gas pipeline failures by cause over the period 1970 to 2010 for the gas pipelines in Europe.

¹⁹ *European Gas Incident Group.*

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*Figure 4.6 – Distribution of Gas Pipeline Failure by Cause
(EGIG, 2011: 21)*

This data shows that the most significant cause of gas pipeline failures is related to third party activity. While the EGIG data is useful, it is of limited value for a number of reasons. The public access to the data is limited to graphical rather than tabular format, with the result that the graphs may be incorrectly interpreted. In addition none of the available datasets make reference to the population density (location class) of the site of the failure (Mather et al., 2001: 28). This lack of information about the population density is unfortunate given the correlation between failure and third party interference. Pipeline codes use the population density to determine the location class and therefore wall thickness requirements in order to mitigate third party damage to the pipeline.

The effects of third party interference are highlighted in the following extract from a pipeline accident brief of the rupture and ignition of a gas pipeline in Texas in 2010:

On June 7, 2010, at 2:40 p.m., a truck-mounted power auger (auger truck) operated by C&H Power Line Construction (C&H) struck and punctured a 36-inch-diameter natural gas transmission pipeline operated by Enterprise Products Operating, LLC2 (Enterprise). C&H, a contractor working for Brazos Electric (Brazos), was using the auger truck to dig holes for the installation of new electric service utility poles. The accident occurred about 45 miles southwest of Fort Worth, Texas, near the town of Cleburne. The natural gas ignited and killed the auger operator and burned six workers, who were transported to a nearby hospital for treatment. The pipeline had a maximum allowable operating pressure (MAOP) of 1,051 pounds per square inch, gauge (psig) and was operating at 950 psig at the time of the accident. Total property damage and clean-up costs were estimated to be \$1,029,000.

(NTSB, 2013: 1)

The pipeline suffered a full-bore rupture for a length of over 110 feet (Figure 4.7), propelling the 60 ton auger truck over 100 feet killing the operator.

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Figure 4.7 – Ruptured Section of Pipeline (Texas 2010)
(NTSB, 2013: 8)

In the report carried out for the Health and Safety Executive (HSE) into the mitigation measures for third party damage to gas pipelines, Mather et al. confirmed that the data for the United States, Europe and the UK agreed about the failure rates due to third party interference. They also recommended that further research be conducted to identify the potential impact on an aging pipeline infrastructure of the combination of corrosion and damage due to third party interference. Although this would not affect the failure frequency, it could affect the extent and probability of pipeline failure (2001: 55).

Given that the incident of gas pipeline failures is similar across Europe and the United States, it is notable that the incident rate in Australia is only 20 percent of the international mean failures for gas pipelines (Tuft and Cunha, 2013: 124). The historical failure rate for all incidents is 0.063 failures per 1000 km-year, which is significantly lower than the figures for Europe and the United States, which are between 0.10 and 0.35 per 1000 km-year respectively, with the underlying exposure being 6.84×10^5 km-year (ibid: 128). The three areas that the authors focused on were the validity of the data, the construction or environment differences, and PIM. The research confirmed the validity of the data, with the

data covering a similar period as the UK data. The method and level of reporting supported by legislative requirements presents a compelling case for the validity of the data. In part, the lower failure rate is attributed to the fact that approximately 80% of the pipelines were built after 1980, with improved coating materials and application over older pipelines (ibid: 132). However, this does not explain the much lower rates of failures due to third parties and the authors recommend that further investigation be carried out as to the operational monitoring and maintenance processes.

It is notable that (Tuft and Cunha, 2013) did not consider the potential variations in wall thickness requirements across (ASME, 2012a), (IGEM, 2008) and (SA, 2012) standards. In their paper, (Goodfellow and Haswell, 2006: 1095) conclude that the risk levels for location classes 1 and 2 (ASME, 2012a) are similar to those in for area type R (IGEM, 2008). However, they point out that the design approach of (IGEM, 2008) in addressing the higher levels of land management in the UK leads to the area type S (IGEM, 2008) having a considerably lower risk than that associated with the equivalent location class 3 (ASME, 2012a).

4.3.2 Approach

The standards governing the installation of gas transmission pipelines recognise that third party interference is the main cause of pipeline failures and consequently reduce the design factor of the pipeline as the number of properties in proximity to it increases. The (ASME, 2012a) standard identifies four location classes, initially based on the number of buildings intended for human occupancy within a quarter of a mile of the pipeline over a random 1 mile length of the pipeline (ASME, 2012a Section 840.2.1). Where the buildings have multiple dwelling units such as apartments, each dwelling unit is considered as a building for the purposes of the location class determination. The code further sub-divides location class 1 into two divisions (1 and 2). Division 1 has a design factor of 0.8 and division 2 has a design factor of 0.72. The definition of the (ASME, 2012a) location classes are summarised in Table 4.5.

Location Class	Design Factor	Definition
1 (Div 1)	0.80	Less than 11 buildings
1 (Div 2)	0.72	Less than 11 buildings
2	0.60	Greater than 10 and less than 46 buildings
3	0.50	Greater than 45 buildings
4	0.40	Where buildings with greater than 3 floors are prevalent

*Table 4.5 – ASME B31.8 Location Class Definitions
(ASME, 2012a: Section 840.2.2)*

However, the code also requires the consideration of areas where concentrations of people occur in areas in location class 1 or 2 (ASME, 2012a: Section 840.3). These high consequence areas (HCA) take account of multiple occupancy buildings such as places of worship, schools and hospitals and outside organised recreational areas. Where HCA occur in location classes 1 and 2, the area covered by the HCA must meet the requirements of location class 3. The extent of the HCA is determined by the potential impact radius (PIR), which is calculated using Equation 4.7.

$$r = 0.00315 \times od \times \sqrt{p} \quad (\text{Eq. 4.7})$$

where

r = Potential Impact Radius (m)

od = Outside diameter of the pipeline (mm)

p = Internal pressure (kPa)

Equation 4.7 Potential Impact Radius ASME B31.8s (ASME, 2012b: Eq. 1)

Using the PIR from the boundary of the building or open area, the HCA is defined as shown in Figure 4.8.

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*Figure 4.8 – Determination of High Consequence Area
(ASME, 2012b: 9)*

The initial pipeline corridor for the purposes of evaluation of location class is based on the code requirements (ASME, 2012a: Section 840.2.2) or the PIR as determined using Equation 4.7 – whichever is greater. In addition, where there might be potential re-routes during the design, additional property information is gathered in these areas.

By classifying satellite imagery, an initial assessment of the location of all properties within the route corridor is carried out. This information can be used to perform a preliminary location class assessment, though it is limited because the multiple occupancy and areas of concentrations of people cannot be identified. Using this information as a basis, a field investigation is carried out during the route selection phase to identify the buildings, habitation status, multiple occupancy requirements, and other metadata. Potential areas of concentration are also identified. This field verified data is then brought into the AEGIS and the location class determination is re-run.

4.3.3 Discussion

Although the classification of gas pipelines according to population density is well established through standards, the application of GIS to the solving of engineering geospatial problems is still not widely used by engineers within the pipeline industry. This is due to engineers not being familiar with geospatial tools – a deficiency that the proposed model seeks to address.

This module has been included within the AEGIS to demonstrate the value of empowering engineers to solve geospatial problems within an environment that they are familiar with – namely CAD. Additionally, it allows the rapid re-calculation of the location class as the

route matures, ensuring consistent verified reporting for each route revision. If additional code modules were created for other standards such as exist in the UK and Australia, then it would be possible to gain a better understanding of the subtle variations between standards, thereby enabling the engineer to make a more informed decision relating to the selection of codes and their application outside the original area of their scope.

Chapter 5

ENVIRONMENTAL ENGINEERING

As part of the objectives (**Research Objective 2d**), an element of environmental engineering was incorporated in the system. In selecting what to include, it was decided to investigate the potential for estimating the soil erosion risk using remote sensed data. The rationale for selecting this area was that it had not already been done and the significance of the environmental impact of soil erosion. The supporting data including input data, summary tables of results and maps are presented in Appendix D.

This is in part based on research initially undertaken as part of a project for a MSc in Geographic Information Science (Winning, 2013b), which proposed a GIS method for estimating the soil erosion risk for a pipeline route using public domain data. The environmental importance of soil erosion was highlighted in a presentation at the Commonwealth Business Council's Uganda Investment Forum in Kampala (Winning, 2013a).

Whereas this earlier work identified the soil erosion risk for a specific pipeline route, the subsequent research proposed a method enabling any route within a broad 10 km corridor to be dynamically assessed for the potential soil erosion risk during the design phase of the project. Integrating this method and moving this GIS based activity into the CAD model enables automatic recalculation of the soil erosion risk as the route changes. This enables the soil erosion risk to be addressed proactively rather than just reactively in the route selection phase of the design. This part of the research was published in the peer-reviewed journal *Biosystems Engineering* (Winning and Hann, 2014) and presented at the ESRI European User Conference in Split, Croatia (Winning, 2014b).

In earlier research undertaken for the dissertation for an MSc in Geographical Information Science, a method of estimating the potential soil erosion loss for a pipeline route using remote sensed data was developed. The method generated a tabular output of the estimated soil loss for the pipeline route by chainage, aggregated into 1 km sections. Although the method enabled the estimation of the soil erosion loss earlier in the project, it had a number of limitations, the main one being the requirement for a soil erosion specialist to perform the analysis and the limitation for automating the process.

While this type of analysis can clearly be automated through code or the ArcGIS Model Builder, because of these limitations it is not recommended. It is vital that the analyst has a clear understanding of the uncertainties within the model and is able through experience and the application of sound engineering methods to correctly interpret the results obtained. By developing a 'black box' solution there is a risk that the results will not be correctly interpreted.

(Winning, 2013b: 61)

Based on this earlier research, this chapter proposes a method to determine the individual components of the USLE in order to enable the AEGIS to estimate the soil erosion risk for the route as it changes. This approach resolves the concern in the previous research with respect to the automation of the SERA and the requirement for the environmental engineer to review the output of the SERA at each route revision.

Section 5.1, 5.2 and 5.3 present précises of the literature review, methodology and results from this earlier research and are included to provide context to the revised method presented in Section 5.4, which builds on this previous work.

5.1 Supplementary Literature Review

Soil erosion is a natural process that is significantly affected by anthropogenic activity that may be defined as:

Soil erosion is the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere.

(Bowyer et al., 2009: 2)

Although the main cause of soil erosion is poor land management practices, major construction activities can lead to increased soil loss if post construction re-instatement does not consider the need to prevent soil loss prior to the establishment of the bio-restoration of the disturbed land.

While the process of soil erosion is the same whether due to erosion by wind or water, the mechanics of the process are different. The factors governing soil loss are those of geology, soil type, surface cover, precipitation, hydrology, land use and geomorphology. Although soil erosion by water is the dominant process both globally (Toy et al., 2002: 25) and in particular to soil loss due to construction activities (Pudasaini et al., 2004), a review of the mechanics of both processes are given.

Soil erosion is a three-stage process. In the first stage (detachment), soil particles are detached by either water or wind. In the second stage (transportation), the soil particles are transported either as sediment or as airborne particles, sometimes for considerable distances. The final stage (deposition) occurs when there is insufficient energy to maintain the transportation of the soil particles (Morgan, 2005: 11).

5.1.1 Soil Erosion

Erosion due to water occurs when the shear stress generated by the impact of the rainfall and sheet erosion overcome the resistance of the soil to these forces (Bradford and Huang, 1996: 61). In modelling soil erosion due to water, the forces exerted by rainfall impact are important and have been the subject of research (Koutsoyiannis et al., 1998, Pudasaini and Shrestha, 2008).

Knowledge of the relationship between rainfall intensity and kinetic energy and its variations in time and space is important for erosion prediction.

(van Dijk et al., 2002: 1)

The detached soil is transported as sediment, until the final stage of deposition occurs as the energy necessary to maintain the transportation reduces below the frictional forces of the ground.

Soil erosion due to water is defined according to the severity of the erosion. Sheet erosion occurs when the soil loss is uniform and thin layers of soil is detached and the flow is unconfined. This is sometimes referred to as inter-rill or overland flow. This can lead to the formation of rills, which form at a critical distance down the slope as the sheet flow becomes

increasingly more channelled. Rills are characterised as temporary and in agricultural land are ploughed out. Finally, as the erosion becomes more confined gullies are formed which become permanent topographical features. These features are shown in Figure 5.1.

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Figure 5.1 – Erosion Types (Sheet, Rills and Gullies)

(Forestry Nepal, 2013)

In the case of soil erosion due to wind, the detachment occurs when the cohesive and gravitational forces are overcome by the force of the wind. Unlike erosion due to water, the sediment size and density has a much greater impact on the transportation stage of the erosion process (Abu-Hamdeh et al., 2006, Zachar, 2011). The transportation stage due to wind erosion is somewhat more complex than that due to water erosion (Figure 5.2).

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Figure 5.2 – Processes of Wind Erosion

(WER, 2014)

Where the soil particles have a diameter in excess of 0.5 mm, they are transported along the surface when the forces exerted by the wind are sufficient; this process is called creep. With soil particles less than 0.5 mm in diameter but larger than the fine particles that are less than 0.1 mm, tend to be lifted by the wind and transported for relatively short distances before falling back to the ground. This process is termed saltation (Harmon and Doe, 2001). This process of saltation is responsible for the creation of ever finer particles, a process termed attrition. Finally, as the soil particles size decreases very fine sediment is suspended in the air and can be transported for considerable distances (Lyles, 1988: 93).

5.1.2 Erosion Control for Pipelines

In addition to the environmental issues due to soil loss already discussed, erosion control for buried pipelines is important for a number of reasons. For construction sites where heavy plant is to be used, the topsoil is removed and stored and the plant operated on the subsoil surface. On reinstatement, rates of bio-restoration are generally poorer for two reasons. Firstly, the heavy plant compacts the subsoil, reducing the infiltration rate of the subsoil leading to reduced porosity (Morgan, 2005: 2). Secondly, if over compaction of the reinstated topsoil occurs, this increases the soils bulk density inhibiting plant growth and further reducing the bio-restoration rate (Daddow and Warrington, 1983: 11). Specifically for pipelines, soil erosion on the reinstated RoW may lead to the formation of rills and gullies on slopes with the potential to expose the pipeline if additional control measures are not put in place.

Inappropriate construction practices and errors in design are a major cause of erosion along many pipeline corridors.

(Morgan, 2005: 170)

Erosion control for pipelines is classified as either temporary or permanent. Temporary erosion control measures such as silt fences and sediment traps typically seek to mitigate the impact of off-site effects, in particular to protect sediment discharge into watercourses. Silt fences are used when the slope is not great and therefore the volume of sediment is low. On steeper slopes, sediment traps, which may be retained as permanent erosion control measures are used. Sediment traps enable the sediment to collect, allowing clean water to discharge into the watercourse. Sediment traps need to be correctly sized and maintained with the collected sediment being placed back onto the pipeline RoW (Fifield, 2004: 6-21).

Permanent erosion control measures include wicker fences, diversion berms, gabions and stone lined waterways. The choice of erosion control method is closely related to the angle of the RoW. With smaller angles, wicker fences have been used (Figure 5.3) to provide permanent erosion control measures where it has been necessary to reduce the sediment discharge into watercourses during storm events while the bio-restoration matures.

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*Figure 5.3 – Double Wicker Fence and Rock Dam
(Morgan, 2005: 236)*

Diversion berms consist of a number of small mounds placed perpendicular to the RoW that are covered in a geotextile membrane (Hann and Morgan, 2006: 597). The purpose of these features is to reduce the velocity of the surface water, thereby reducing the energy to detach the soil and to divert the water across the RoW to undisturbed and vegetated slopes (Morgan et al., 2003: 249). Where berms are not sufficient on their own, stone waterways may also be employed. Figure 5.4 shows the permanent erosion control measures for a pipeline in Azerbaijan. There is a central stone waterway with berms on both sides and a sediment trap at the bottom of the slope. This sediment trap is constructed of gabions²⁰ and geotextile membrane. At the bottom right hand edge of the sediment trap, river training works of gabions have been installed to prevent bank erosion to protect the sediment trap (Robert, 2003: 62). These erosion control measures are designed to mitigate soil loss during the bio-restoration of the RoW (Coppin and Richards, 1990, Gray and Leiser, 1982).

²⁰ Gabions are baskets made from galvanised wire that are filled with rock.

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Figure 5.4 – Stone Waterway and Diversion Berms (Hassan Su - Azerbaijan)

The final component of the permanent erosion control measures is the bio-restoration of the RoW. To reduce the time required for bio-restoration and mitigate the impact of storm events, quick-growing plants, native to the area are used. Once established these help to provide soil structure as well as reducing soil moisture by evapotranspiration²¹.

In order to determine the erosion control measures required, an estimate of the potential soil loss and therefore the soil erosion risk classification along the RoW must be determined. This estimation is based on the condition of the newly reinstated RoW, that is, with no bio-restoration and bare soil. Based on the soil erosion risk classification, the erosion control measures are selected to ensure maximum sustainable use of the land, minimise the impact to the environment. This is called the soil loss tolerance (Morgan, 2005: 152). Given the very slow rate of soil formation, a more practical approach for estimating the soil loss tolerance is to assume that the area is in equilibrium prior to construction and that the soil loss tolerance is therefore equal to the current soil loss rate (Morgan, 2005: 152).

Clearly, the aim is to cause no environmental damage. However, from a practical perspective, the best that can realistically be achieved is to minimise the environmental

²¹ *The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces, and by transpiration from plants.*

impact of these major infrastructure projects. Based on this, (Morgan, 2005) proposes a pragmatic approach for construction projects in order to determine an acceptable soil loss tolerance. By deciding on the level of environmental damage that is acceptable using field observed criteria (Table 5.1) as a guide, a soil tolerance equating to classes 1, 2 or 3 could be selected; erosion classes greater than 3 would lead to unacceptable levels of soil loss. This enables soil tolerance levels to be set to local conditions and to set local objectives (ibid: 153). In order to quantify the erosion risk, a classification system is used (ibid: 88) ranging from class 1 (very slight) to class 7 (catastrophic) based on the annual soil loss (Table 5.1).

Erosion Class	Verbal Assessment	Soil Loss (t/ha year)
1	Very slight	< 2
2	Slight	2 – 5
3	Moderate	5 – 10
4	High	10 – 50
5	Severe	50 – 100
6	Very severe	100 – 500
7	Catastrophic	> 500

*Table 5.1 – Classification of Soil Erosion for Field Appraisal
(Morgan, 2005: 88)*

In assessing the erosion control measures to be adopted, consideration is given to the impact of storm events that might occur prior to the completion of the bio-restoration of the RoW. The time required for bio-restoration to complete can be extended if the reinstatement of the pipeline occurs outside of the planting season. Storm events are defined by their intensity, duration and the return period. Conservative values for these factors in rural areas have been defined as:

A design storm can be based on the 10-minute peak intensity and the 1-hour volume of rainfall expected with a 10-year return period.

(Hann and Morgan, 2011: 7).

Based on the classifications given in Table 5.1, where the erosion classification is greater than 3, erosion control measures will be necessary in order to ensure that the soil loss is limited to $10 \text{ t ha}^{-1} \text{ year}^{-1}$ (erosion class 3). Where these conditions are encountered and there is concern for sediment discharge into watercourses, a reduced soil loss of less than $5 \text{ t ha}^{-1} \text{ year}^{-1}$ (erosion class 2) would be selected as a more suitable target of the erosion control measures (Hann and Morgan, 2011: 9).

5.1.3 Modelling Soil Loss

In order to address the soil erosion issues in the United States in the 1920s, Hugh Bennett started recording the rates of soil loss and the impact of various measures to mitigate these losses. From this, mathematical models have been developed to help predict the potential soil loss given a range of input values. The first of these, the USLE was developed in 1965 (Wischmeier and Smith, 1965) and the Revised Universal Soil Loss Equation (RUSLE), issued in 1978 (Wischmeier and Smith, 1978). Since then other models have been proposed, including the Morgan-Morgan-Finney (MMF) (Morgan, 2001, Morgan and Duzant, 2008) and the European Soil Erosion Model (EUROSEM) (Morgan et al., 1998). These later models offer refinement such as the consideration of seasonal variation but in doing so are more complex and more importantly require inputs that can only be determined using field studies, sometimes over extensive periods. Given that the components of the model are to be derived from remote sensed data, the simpler USLE model has been adopted. Figure 5.5 shows the components for the USLE and the factors that influence them.

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*Figure 5.5 – Components of the Universal Soil Loss Equation
(Hann and Morgan, 2011: 13)*

5.2 Determining the Individual Factors of the USLE

While the USLE is described as universal, its database is restricted to the soils east of the Rocky Mountains; however, further research has been conducted which shows that it can be used in other geographical areas (Dabral et al., 2008, Roose, 1977) and applied to the construction industry (Gray and Sotir, 1996, Gray and Leiser, 1982). As previous work conducted in Azerbaijan and Georgia was based on the USLE (Equation 5.1), this equation has been used for comparative purposes in this study rather than models such as the RUSLE (Renard, 1997) or the MMF (Morgan et al., 1984). The area of the study is shown in Map 1 and Map 2 (Appendix D5).

$$A = R \times K \times S \times L \times C \times P \quad (\text{Eq. 5.1})$$

where

A = Mean annual soil loss (t ha^{-1})

R = Rainfall erosivity factor ($\text{MJ mm ha}^{-1} \text{h}^{-1}$)

K = Soil erodibility factor ($\text{t ha h ha}^{-1} \text{MJ}^{-1} \text{mm}^{-1}$)

S = Slope steepness factor (dimensionless)

L = Slope length factor (dimensionless)

C = Crop management factor (dimensionless)

P = Erosion control practice factor (dimensionless)

Equation 5.1 Universal Soil Loss Equation (USLE)

The dimensionless factors S , L , C and P are ratios of soil loss observed from a standard U.S Department of Agriculture (USDA) erosion plot.

The determination of the USLE components are based on the method based on previous research (Winning, 2013b). In the previous research, the potential soil loss for a given pipeline route was determined and the potential soil loss calculated for 1 km sections of the pipeline route. The rainfall erosivity factor (R) and the soil erodibility factor (K) are determined using the same methods proposed by (Winning and Hann, 2014), but are used to determine the factors for a wider area of interest as raster datasets. These are reviewed by a soil erosion specialist and then converted into vector datasets for importing into the AEGIS. In order to provide context for this revised method, the method for determining the R and K factors of the USLE from remote sensed data, based on the previous research are summarised in the following sections.

5.2.1 Rainfall Erosivity Factor (R)

The kinetic energy of the rainfall based on the rainfall intensity is determined using Equation 5.2 (Laws and Parsons, 1943):

$$E = 0.119 + 0.0873 \log_{10} I \quad (\text{Eq. 5.2})$$

where

E = Kinetic energy per mm of rain (MJ/ha.mm)

I = Rainfall intensity (mm/h)

Equation 5.2 Rainfall Kinetic Energy Equation (Laws and Parsons, 1943)

Meteorological information is taken from the World Meteorological Organisation (WMO)²² (Appendix D5 – Map 3). Weather stations in the area of the proposed pipeline corridor are imported into the GIS. Based on the stations with highest annual rainfall, the rainfall erosivity factor (R) was determined for the weather station in Yevlax in Azerbaijan (Table 5.2) using the method proposed (Winning and Hann, 2014).

Description	Value
Elevation (m)	15
Annual rainfall (mm)	339
Rainfall in wettest month (mm)	49
Rainfall of the wettest Month as a percentage of the annual rainfall	14
Percentage of monthly rainfall in a single day (assumed)	90
Daily storm rainfall (mm)	44.10
Erosive rainfall intensity (I) (mm/h) (Wischmeier and Smith, 1978)	75
Percentage of erosive storm rainfall (Hudson, 1995)	40
Rainfall intensity over 30 minutes (I_{30}) (mm/h) (Morgan, 2005)	22.05
Erosive rainfall (mm)	17.64
Kinetic energy per mm of rain E (Mj/ha.mm) (Equation 5.2)	0.28
Rainfall erosivity factor R (Mj.mm/ha.h) (Equation 5.3)	110
Adjustment for rainfall erosivity factor R per metre of elevation (Mj.mm/ha.h) (McIsaac, 1990)	0.07

Table 5.2 – Determination of the R factor (Yevlax, Azerbaijan)

The adjustment for elevation of the weather station is calculated as:

²² The organisation responsible for the collection and dissemination of world metrological data through the United Nations Statistics Division (UNSD) of the Department of Economic and Social Affairs (DESA)

The kinetic energy of the rainfall is inversely proportional to the density of air raised to the power of 0.9 and the determination of the kinetic energy of the rain is based on studies that have been carried out at low altitudes. Therefore an adjustment to the rainfall erosivity factor R is required with an increase of 7% for every 1000 m of elevation (McIsaac, 1990).

(Winning, 2013b: 39)

The R factor is calculated using Equation 5.3 using the kinetic energy determined using Equation 5.2.

$$R = EI_{30} \quad (\text{Eq. 5.3})$$

where

R = Rainfall erosivity factor (MJ.mm/ha.h)

E = Kinetic energy per mm of rain (MJ/ha.mm)

I_{30} = Maximum rainfall intensity over a 30 minute period multiplied by 2 (mm/h)

Equation 5.3 R Factor for the USLE Equation

5.2.2 Soil Erodibility Factor (K)

The soil erodibility factor K is based on the organic content of the soil. It has been established that soils may be grouped by their organic content to derive the K factor; based on 0.5%, 2% and 4% organic content (Mitchell et al., 1980). Clearly, it is not possible to determine soil type and therefore organic content using remote sensed data. However, the use of remote sensed data to calculate the normalised difference vegetation index (NDVI)²³ for soil mapping (Büttner and Csillag, 1989, Mathieu et al., 1997) is well established. This method can determine data on bare soils to an accuracy of 85% (Verbyla and Richardson, 1996: 423).

Using this approach, a method is proposed based on the premise that healthy vegetation is likely to indicate soils with a higher organic content (Winning and Hann, 2014). In a similar way as to the method adopted for the determination of the R factor, a raster dataset is created of the vegetation type from LANDSAT imagery (ESRI, 2014) (Appendix D5 – Map 4). By assigning the K factor values (Mitchell et al., 1980) based on the vegetation classification (Appendix D5 – Map 5), a raster dataset is created of the K factor values. These are then

²³ *This is an index of plant photosynthetic activity. Active vegetation absorbs most of the red light, while reflecting most of the near infrared light. Vegetation that is dead or stressed reflects a greater amount of red light and less near infrared light.*

checked by a soil erosion specialist and then exported as a vector dataset for inclusion in the AEGIS.

5.2.3 Slope Steepness (S) and Slope Length (L) Factors

These critical components of the USLE can be accurately determined using a digital elevation model (DEM). Currently there are two public domain datasets available with almost worldwide coverage. These are the advanced space-borne thermal emission and reflection radiometer (ASTER) at a resolution of 30 m and the shuttle radar topography mission (SRTM) at 90 m resolution. As the requirement is to determine the potential soil erosion loss at 1 km intervals, the SRTM data was selected (Appendix D5 – Map 6).

To provide a visualisation of the slope along the pipeline route in the study, slope analysis has been performed (Appendix D5 – Map 7). These factors are directly calculated within the AEGIS for the current route using Equation 5.4 (Morgan, 2005: 120).

$$LS = \left(\frac{x}{22.13} \right)^n \times (0.065 + 0.045s + 0.0065s^2) \quad (\text{Eq. 5.4})$$

where

x = slope length in metres

s = slope gradient as a percentage

n = exponent for slope steepness (Table 5.3)

Equation 5.4 LS Factor for the USLE Equation

Slope Gradient (%)	Exponent
≥ 5	0.5
$< 5 > 3$	0.4
$\leq 3 \geq 1$	0.3
< 1	0.2

Table 5.3 – Exponent for Slope Steepness for the USLE

5.2.4 Crop Management Factor (C)

This is set for the project and stored within the AEGIS. Although a value of 1 represents bare soil, slightly higher values are used to simulate the over compaction of the subsoil and the reduced infiltration rates typical of newly reinstated construction sites. For the study, a value of 1.2 was used.

5.2.5 Erosion Control Practice Factor (P)

This is also set at the project level within the AEGIS and is set to 1.

5.3 Results

In the previous research, the imagery was resampled to the same resolution as the largest spatial resolution dataset (SRTM data at 90 m). Using the inputs for the USLE equation described, the estimated soil erosion rate and risk classification were determined along the pipeline route at a spatial resolution of 90 m. This data was then aggregated to 1000 m sections, which is typically the level of spatial resolution used for this type of survey on long distance pipelines (Appendix D5 – Map 8). The values obtained using this method was compared to the erosion risk classification determined by site investigation (Appendix D5 – Map 9).

The calculated soil erosion risk varied from the field observations between 2 and -4. As can be seen (Table 5.4), over 96% of the values obtained using this method were within the range of ± 1 soil erosion classification as determined in the field.

Difference of soil erosion risk between Calculated and Field Values	Number of Points	Percentage
-4	81	1.3
-3	70	1.2
-2	82	1.4
-1	1446	24.0
0	4169	69.1
1	181	3.0
2	1	0.0
Difference of ± 1 erosion class		96.1

Table 5.4 – Difference of the Calculated and Field Values

The areas where this method failed to identify the potential soil erosion were major rivers and areas of seismic crossings, which would be included in the field verification irrespective of the results of the remote sensed analysis.

5.4 Discussion

The USLE is more sensitive to the *LS* factor, which, with the exception of localised slopes within the spatial resolution of the DEM dataset, is accurately determined using this method. The inability to identify correctly the soil type will have a greater impact on areas where the pipeline route traverses predominantly flat terrain.

The variance between the calculated and field values is shown in Figure 5.6.



Figure 5.6 – Overview of the Variation in Erosion Risk Classification

As can be seen in Figure 5.6, there are two areas where the variance was greater than 1; these are shown in Figure 5.8 and Figure 5.10. In the eastern area of Azerbaijan (Figure 5.8), there are five areas where there was a significant difference between the erosion risk as calculated using this method and the field-determined classes.

This section of the route crosses an area of unconsolidated materials such as marls and shales covered with silt-rich soils, which are generally characterised by high erosion rates, low

infiltration rates and high erodibility. Erosion in this area results from surface runoff, subsurface flow (piping or tunnel erosion) and mass movement. Water movement through the material along concentrated flow paths leads to washout and the development of subsurface channels. Continued erosion results in the collapse of the channels and the formation of gullies. Further erosion is then by surface flow along the floor of the channels and the collapse of the gully sidewalls through mass soil failure. Figure 5.7 shows severe gully erosion off the route in the Sangachal region of Azerbaijan (Area 3A Figure 5.8).



Figure 5.7 – Typical Gully Erosion in Erodible Soils near Sangachal, Azerbaijan

Due to the reduced level of accuracy in determining the soil type through this method combined with localised ridges, the areas 3A and 3C (Figure 5.8) vary from the field determined values by -3 and -2 respectively. The area 3B (Figure 5.8) is the 150 m wide crossing of the Djeyrankechemes River; this river has been identified as the width is greater than the spatial resolution of the DEM. The riverbanks are steep and consist of silts and very fine sands, with limited vegetation in the catchment area upstream; while the water level at this point is usually low, it is subject to frequent flash floods.

The South Caspian Basin is an area of intense seismic activity with more than 400 active mud volcanoes²⁴ mainly located in the east of the country; more than half of the total mud volcanoes in the world (Planke et al., 2003: 260). The point marked 3D (Figure 5.8) is the location of a seismic fault crossing on the pipeline route and poses an increased soil erosion risk due to the construction methods required to minimise failure of the pipeline in the event of seismic activity. Where the pipeline crosses a seismic fault, the trench width is increased and lined with a geotextile membrane and backfilled with a uniform granular material to facilitate lateral movement of the pipeline within the trench in the event of a seismic event.

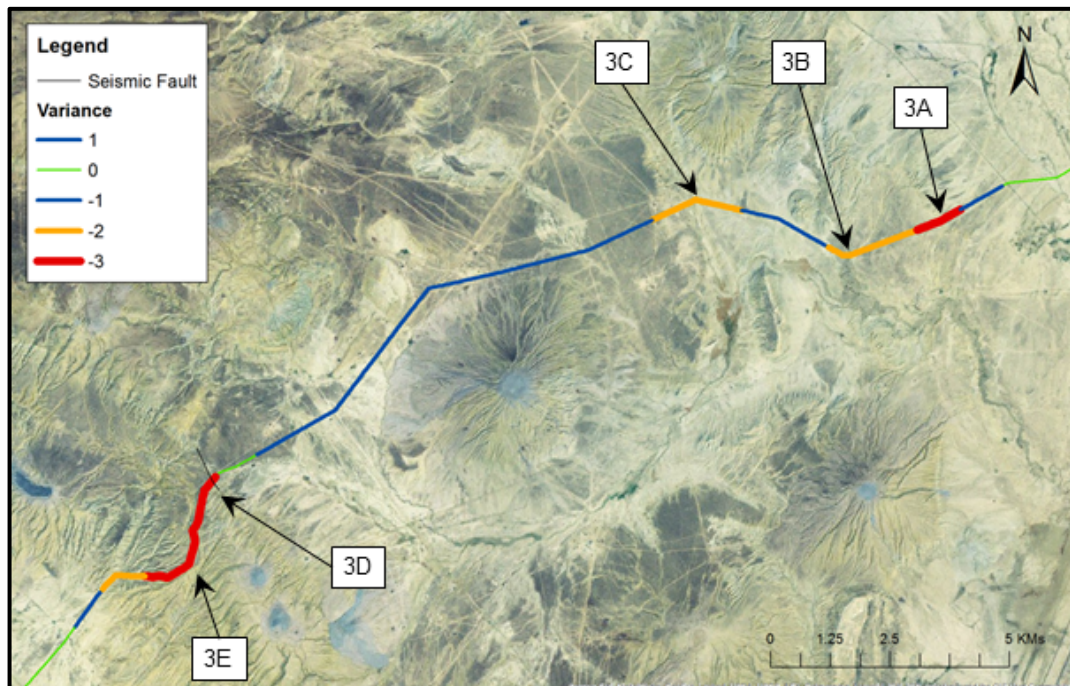


Figure 5.8 – Area of High Erosion Risk (Azerbaijan - East)

The area marked 3E follows numerous ridge lines passing close to a number of gryphons – small steep sided cones extruding mud during the dormant phase (ibid: 259).

²⁴ *A vent in the earth's surface through which escaping gas and vapour issue, causing mud to boil and occasionally to overflow, forming a conical mound around the vent.*



Figure 5.9 – A 20m Diameter Gryphon at Location 3E

The second area where the difference between the calculated erosion risk and the field determined values is in the west of Azerbaijan, shown in Figure 5.10.

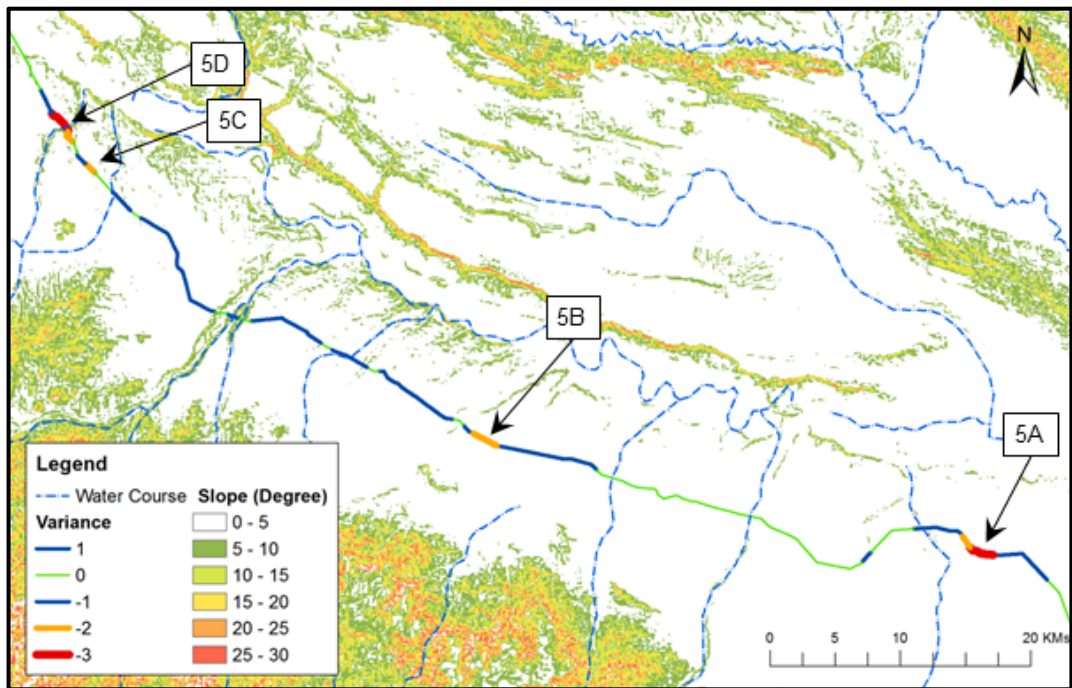


Figure 5.10 – Area of High Erosion Risk (Azerbaijan - West)

Four major areas were identified with significant difference between the calculated and field observed values. Points 5A, 5B and 5C (Figure 5.10) are all areas with localised slopes with lengths less than the spatial resolution of the DEM. The field visit identified that these areas were generally characterised by poor land management practices leading to a higher erosion risk – information which cannot be determined using high level remote sensed data. Point

5D (Figure 5.10) is the crossing of the Hassan Su River. This is a deeply incised meandering river with banks of gravels in decomposed shales and clays subject to seasonally high flow rates.

The soil erosion risk classification for the field collected data and the GIS determined data (GIS calculated), are shown in Figure 5.11.

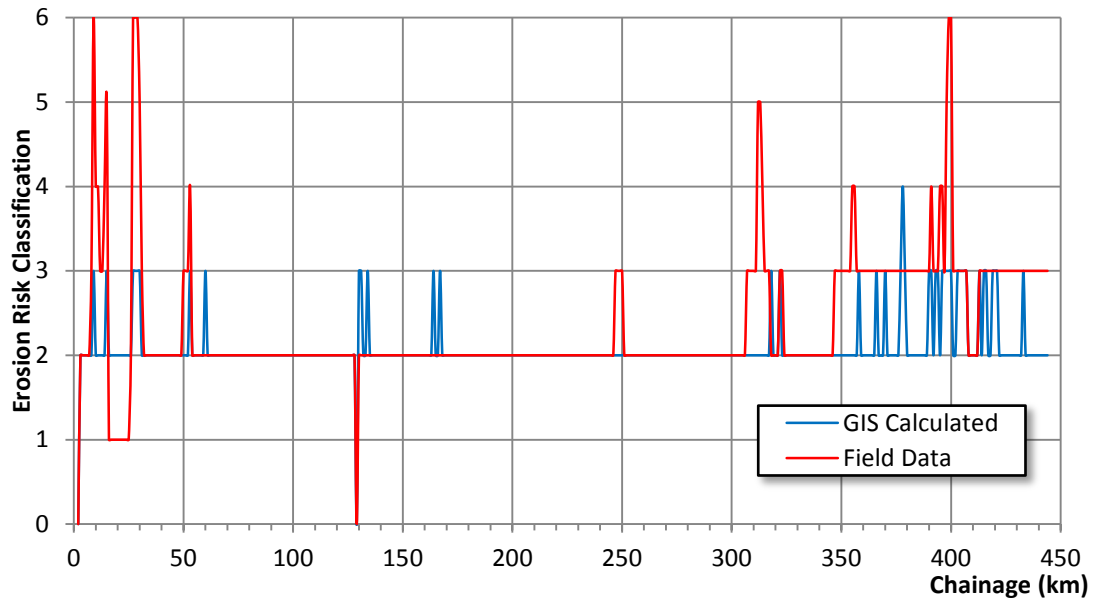


Figure 5.11 – Comparison of Field and GIS Data in 1,000 m Aggregated Sections

As all known areas of seismic activity and major river crossings would be included for field review, Figure 5.12 shows the modification of Figure 5.11 to remove these points. The ordinate represents the difference between erosion risk classifications between the modified results obtained from the model and the field study.

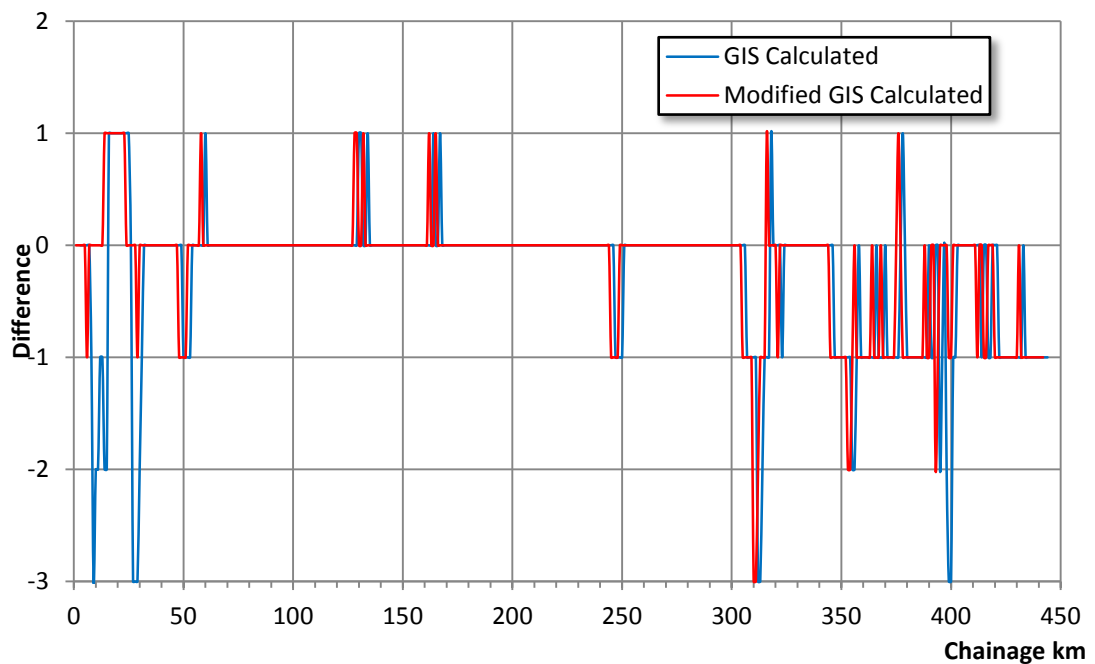


Figure 5.12 – Modified GIS Calculated and Field Values 1,000 m Sections

The proposed method enables the erosion risk to be quickly reassessed for comparison of different route options or for revisions to the route; and in addition to providing an early indication of the soil erosion risk, it will enable the field verification to be more targeted. Early identification of the environmental impacts of major infrastructure engineering projects is essential and given the relative ease and minimal cost of this type of study, it is recommended that this method should be seen as best practice in the preliminary stages of pipeline route selection.

Having created and reviewed the datasets in ArcGIS for the rainfall erosivity (R) and soil erodibility factors (K) for the USLE, these are then added to the AEGIS. The slope steepness (S) and slope length factors (L) are determined within the AEGIS using the DEM. Finally, the crop management (C) and erosion control practice (P) factors are set within the AEGIS at the project level. This enables the soil erosion loss and risk to be dynamically estimated as the pipeline route changes and matures; it also enables route option comparisons based on the potential soil erosion risk. This approach resolves the issue of the risk of performing this type of analysis in a 'black box' environment (Winning and Hann, 2014), while allowing the pipeline engineer to automatically recalculate the erosion risk as the route changes.

Chapter 6

ENGINEERING DESIGN

This chapter reviews the engineering design processes and methods that form an integral part of the pipeline engineering process. Fundamental to the systems used within engineering design are the issues of open data standards and data interoperability (**Research Objective 2e**) as are the challenges of CGI (**Research Objective 2f**).

The research for Chapters 6 and 7 formed the basis for two conference papers. The novel application of a modified version of the Pipeline Open Data Standards (PODS) database schema to the CAD environment as part of the AEGIS was presented at the PODS User Conference in Houston (Winning, 2014c). The wider issues of data interoperability and the challenges of CGI were addressed in a paper delivered at the ESRI European Petroleum User Group Conference in London (Winning, 2014a).

6.1 Supplementary Literature Review

6.1.1 CAD/GIS Integration (CGI)

The principal differences between the CAD and GIS environments are those of data format, spatial scale of representation (precision) and semantic issues (Akin, 2010a: 66). Improvements have been made recently with respect to the handling of proprietary formats by both CAD and GIS. AutoCAD MAP can import and export to the proprietary ArcGIS shapefile (SHP) format²⁵. ESRI have taken a different approach through the data interoperability extension. They provide direct data access and data translation tools transparently, in addition to the standard import and export of data. The AutoCAD approach provides a basic syntactic interoperability between CAD and GIS within the standard application. Conversely, the ESRI solution goes beyond the syntactic in providing semantic interoperability between other CAD and GIS formats; however, it requires additional licensing and is not a component of the standard system.

Some vendors will continue to sell expensive, high-end CAD and GIS tools for specific analysis and design tasks, as if the professionals who use these separate tools do not interact with each another. However, within most organisations these mapping and engineering professionals must work together efficiently to be successful.

(Curry, 2004: 6)

Although the licensing policy has not changed, the continuing drive for data interoperability was a central theme of the keynote speech at the ESRI European User Group Conference in Split, Croatia (Dangermond, 2014).

The challenges and issues facing the CGI are summed up in two quotations from 2004 – the first from the CAD perspective, the second from GIS. In an Autodesk strategic white paper, Curry stated that

Some professionals maintain an outdated view of CAD and GIS, believing that the two technologies are so distinct that any data integration is impossible. This perception arises because neither technology is well understood by users or vendors of the other.

(Curry, 2004: 6)

²⁵ *A shapefile is a simple, non-topological format for storing the geometric location and attribute information of geographic features. Geographic features in a shapefile can be represented by points, lines, or polygons (areas).*

The ESRI perception of CGI was also one of confrontation. Bill Miller, an ESRI Design Manager was quoted as saying

There used to be a huge gap between CAD and GIS ... But now it's probably more of a collision zone than a gap.

(Miller, 2004: 3)

The analogy of the CGI gap being a collision zone is perhaps due in part to the lack of professionals operating across the two fields, which is seen as a problem (Peachavanish et al., 2006: 71). It is also important to understand that users may be reluctant to master new technology and that sometimes what can be seen as an issue of interoperability may in fact be due to the hesitancy of users to change or modify working processes and practices (Miller, 2004: 3). Both the ease of use and the issues of integration need to be addressed.

Besides agreement on specifications and standards, the next generation of GIS software and tools will be developed based on the concept of ease of use, implementation, and integration.

(Kasccaemsuppakorn et al., 2010: 45)

Akin submits that a successful CGI would present all the relevant information, both spatial and non-spatial, for the entire lifecycle of an asset, persistently, with both precision and interoperability. Furthermore, he envisages that the system should be focused on function rather than form (2010a: 68) – a concept that is central to the definition of the AEGIS.

Until the demand for CGI applications become stronger, a widespread solution to the problem does not seem to be in (sic) the horizon.

(Akin, 2010b: 66)

6.1.2 Data Interoperability and Open Standards

Interoperability is seen as fundamental to build the heterogeneous environment required of successful CGI, with the transition likely to be through the syntactic to the semantic (Peachavanish et al., 2006: 71). Interoperability may be considered as comprising both data interoperability and the use of open data standards. While the two aspects are closely linked, they are quite distinct.

Data interoperability may be defined as follows:

The capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units.

(BS ISO/IEC 2382-1, 1993)

In addition to the problems associated with data interoperability, the lack of interoperability between CAD and GIS leads to inefficiency and increased costs (Akinci et al., 2010: 219). The cost of inadequate interoperability in the U.S. capital facilities industry in 2002 was estimated to be \$15.8 billion per year (NIST, 2004: 6-1); this highlights the real world cost of not addressing this issue. Although similar figures are not available for the pipeline sector, the cost of data interoperability is also seen as a major risk in PIM. The findings of the investigation into the full-bore rupture of a 30-inch intrastate gas pipeline in San Bruno California in 2010 concluded that there were significant failings in the operators' management of their assets. The information about their assets was distributed across the organisation, was poorly connected, and had poor referential integrity (CPUC, 2012). The U.S. legislation – the Pipeline Safety Improvement Act of 2002 – requires pipeline operators to have centralised, computerised records for all their assets.

Pipeline design requires the use of a variety of specialist software systems spanning engineering, design and GIS, which has led to the issues of interoperability between the disparate systems (Akin, 2010a: 56). While the systems themselves do not necessarily need to be interoperable, the data that these systems use is frequently the same, though stored in different formats; in order to share this information across the systems, data interoperability is required. The issues for pipelines are compounded by the complex nature of the relationships between large volumes of spatial data spanning a broad temporal range.

Complex behaviours, however, such as linear referencing for service laterals, and pipe material and size combinations are much more esoteric and are often lost in translation or interoperation efforts.

(Casey and Vankadara, 2010: 151)

At the most basic level, this is achieved by syntactic interoperability through specified data formats and communication protocols (Ouksel and Sheth, 1999: 5). Semantic interoperability builds on the syntactic by providing an ability to automatically exchange data without loss or corruption thereby ensuring meaningful exchange between systems (Heiler, 1995: 271). The aim is to provide syntactic interoperability within the system for abstract and feature classes, making it possible to expand this into semantic interoperability in order to support the transfer of data for user-defined feature classes.

Within the field of pipeline engineering, there are a number of open standards relating to GIS data models. The Integrated Spatial Analysis Techniques (ISAT) data model, initially developed by the Gas Research Institute (GRI), was introduced in 1997 and provided the first pipeline specific data model (McCallum, 2000: 8). It was a relational database schema with 72 tables designed for the management of existing pipelines, though it had no geospatial component (Anon, 2007: 34). Building on the ISAT model, the PODS data model version 2.0 followed in 1998, with 184 tables and 48 sub-models (PODS, 2014); this, like the ISAT model, was not geospatial. The PODS Association recognises the importance of the issue of data interoperability by specifically including it in the guiding principles of the Association (PODS, 2011: 16).

In 2003, ESRI released version 1.0 of the ArcGIS Pipeline Data Model (APDM). In line with the development of previous ESRI data models, the aim was to provide the core components from which the operator could build a spatial pipeline database schema. With the release following only a year after the introduction of the Pipeline Safety Improvement Act of 2002, the focus was on integrity, pipeline inspection, high-consequence areas, and risk analysis as part of the PIM process (ESRI, 2004: 1). A key component of the pipeline data model was the requirement to enable linear referencing of features. Linear referencing, often referred to as either chainage or stationing, is the measure along a linear feature such as a road, railway or pipeline (Irvine and MacLennan, 2006: 212).

Both APDM and the PODS data models have continued to evolve. The PODS ESRI spatial model version 5.1 model has 678 tables in 203 sub-models (PODS, 2014), with support for linear referencing (Sinclair, 2013: 34). At the ESRI European Petroleum User Group (EPUG) Conference in London in November 2014, ESRI announced the introduction of the ArcGIS Location Referencing for Pipelines (ALRP). This will move the geometric and liner referencing into the Geodatabase, imbedding this core pipeline data management functionally into ArcGIS Pro (Allen, 2014). Further work on the issue of data interoperability and open standards was announced in November 2013 by the Open Geospatial Consortium (OGC)²⁶:

²⁶ *An international industry consortium of companies, government agencies and universities participating in a consensus process to develop publicly available interface standards.*

The Open Geospatial Consortium and the PODS Association, Inc. ("PODS"), have signed a liaison agreement to provide value for the members of each organisation. The two organisations have agreed to work together to identify enhancement opportunities between the advanced geospatial interoperability concepts developed within the OGC's consensus standards process and the PODS Association's widely used PODS standard and data model.

(OGC, 2013)

6.1.3 Pipeline Design and GIS

This section reviews the emerging use of GIS within the field of pipeline design. Early work focused on the growing availability and use of remote sensed data to perform preliminary desktop routing. The remote sensed data enables the pipeline engineer to identify infrastructure, land cover and use, and hydrology, while the DEM enables the issues of constructability, pipe sizing and pump station capacity to be explored (O'Connell, 2006: 58). It is important to understand that the hydraulic analysis was still being carried out in proprietary software, using elevation data supplied by the DEM. Other uses included the use of near infrared bands to attempt to identify shallow sub-surface rock in desert areas (ibid: 59). In their article, (Brook and Maclenan, 2007) expand on some of the advantages of GIS for pipeline design. Although the article discusses the entire project life cycle, it is predominantly aimed at the operational phase and the management of existing assets. Where the use of GIS for the design phase is discussed, no mention is made of the requirements for hydraulic analysis as an input into the model.

Later work has started looking at the aspect of pipeline route determination using GIS analysis. A number of papers and articles have espoused the use of GIS for determining the optimum route for pipelines. Given the ability of GIS to perform least cost path analysis coupled with its geospatial tools of kernel density, aggregation and extraction, it is clearly suited to this task. As remote sensed data becomes more readily available, the potential for GIS to determine an optimum pipeline route is enhanced. Much of the work undertaken to date is based on a similar method. Using a variety of data sets covering population density, existing infrastructure, hydrology, archaeology, land use, land cover and environmental constraints, a discrete cost surface is created in GIS. This is based on a weight-averaging of the input maps and data sets (Berry et al., 2004, Delavar and Naghibi, 2007).

The paper by (Feldman et al., 1995), looked at a prototype for GIS pipeline routing for a 51km section of a proposed 700km oil pipeline; they stated that

“The cost of pump stations, however, has not been considered in this analysis.

(ibid: 125)

With the hydraulic design being more sensitive for liquid pipelines and in the absence of any explanation, the only rationale for this decision can lie in the complexity of undertaking the hydraulic analysis within the GIS model.

A similar approach of excluding any form of hydraulic analysis was adopted for the route determination of a 34km route in Iran. This conference paper (Delavar and Naghibi, 2003) was also published as a magazine article (Delavar and Naghibi, 2007).

The paper by (Berry et al., 2004) acknowledges the need to undertake hydraulic and economic modelling as part of the route selection process, with the hydraulic and cost modelling performed on the route selected using the least cost path analysis within GIS by use of external Excel spreadsheets (ibid: 6).

While this approach offers benefits to the more traditional route selections outside of GIS, it still requires an iterative process of defining the route based on criteria available to the GIS and then subsequent hydraulic analysis. The two-stage approach whereby the route is optimised within GIS and by external pipeline hydraulic analysis – is currently the standard approach.

In their paper, (Ebrahimipoor et al., 2009) make no mention of the inclusion of any hydraulic component in the routing algorithm, presumably because the route under investigation had an elevation range of 130m and the length of the pipeline was only 60km. While this approach may be justified for short routes, it clearly calls into question the application of the proposed method to long large-diameter pipelines. The ESRI Route Optimisation Interface (ESRI Utility Team, 2011) proposes a basic least cost path analysis method for pipeline route selection, again neglecting any reference to pipeline hydraulics.

Although (Marcoulaki et al., 2012) include pressure calculations in an appendix, the authors stated that the pump station locations were not considered in the current study because the pipelines were relatively short and the pressure drop low (ibid: 2215). The recent article about GIS for the route selection of a new 42-inch diameter 300-mile pipeline loop for the expansion of the Rockies Express (REX) pipeline also made no mention of hydraulic analysis (Mahrou, 2014).

Another approach has been the application of edge theory to determine the shortest optimum path. Although the pipeline hydraulics are considered, the locations of the pump stations are fixed prior to running the simulation and the analysis is isothermal (Chu and Chen, 2012: 217). However, this approach has potential for further scope, which is discussed in Chapter 9.

6.2 Discussion

Fundamental to the design of the pipeline is the hydraulic design, without which the system will not be able to deliver the product (at worst) or will be economically inefficient (at best).

The design of all pipelines involves achieving an economic balance between the capital cost of the pipeline and its associated pumping or compression facilities on the one hand, and the subsequent annual cost of operating the pipeline on the other; the most significant element of the latter is the cost of energy to propel the fluid through the pipeline.

(Pipeline Industries Guild, 1984: 14)

The aim of the hydraulic analysis of the pipeline is to achieve a hydraulic balance of the system. This occurs when the pump/compressor stations are operating with the same inlet and discharge pressures. A hydraulically balanced system will reduce both operational and maintenance costs of the pipeline. The maintenance costs can be reduced due to inventory requirements for spare parts being minimised through the use of identical equipment across multiple locations (Menon, 2011: 226). The operational cost is reduced as the total power for the system is minimised when the stations are hydraulically balanced (ibid: 266).

As can be seen, previous papers on route selection using GIS have either ignored the complex issue of pipeline hydraulics altogether or have performed the analysis externally and independently of the initial route selection process. In so doing, the hydraulic analysis of the pipeline is not being used to optimise the route selected, only to refine the selected route.

Essential to the AEGIS is the importance of including preliminary hydraulic analysis within the system. In order to achieve this it has been necessary to optimise the way the calculations are performed. Although automated pipeline route selection is not within the current scope of the AEGIS, this is an exciting area for further development and is discussed in Chapter 9.

The other problem facing the engineering designer is that of drawing production. The main challenge facing all engineering design offices competing in a global context is one of cost. The ability to produce high-quality accurate drawings with maximum efficiency is crucial to an organisation's capacity to win work – a challenge that is magnified due to the linear nature of the drawings.

Alignment sheets are typically drawn at a scale of 1:2,500 and show one kilometre of pipeline in plan and profile. The profile is usually exaggerated in the vertical axis by a magnitude of ten in order to identify minor changes in elevation. In mountainous terrain, due to the limitations of space on the drawing, this requires the profile to be cut into sections. The alignment sheet provides all the engineering and environmental information for the entire pipeline. This includes pipeline material properties, depth of cover, construction right of way, third party crossings, protection requirements, geotechnical investigation locations, construction and environmental constraints, pipeline reinstatement requirements, and reference to detailed crossing and station approach drawings. Much of the information shown on the alignment sheets is also present in a number of other documents – including detailed drawings, MTOs, schedules, reports and specifications.

This presents a challenge to the engineering designer in ensuring consistency across all these documents while not affecting the schedule. The solution to these challenges is an integrated model providing single source and automated drawing and document production. This approach enables the system that has been validated, to produce high-quality accurate documentation with minimal additional checking required.

Chapter 7

DEVELOPMENT OF THE AEGIS

The term AEGIS is intended to be generic and encompasses any engineering-specific GIS, irrespective of function. Therefore, the instantiation of the AEGIS created as part of this research is called the Pipeline Integrated Engineering Environment (PIEE); for the purposes of this thesis, the terms are synonymous. However, in this and the following chapter, reference is made exclusively to the PIEE, with the references applying to the specific instantiation of the AEGIS. The SDS (Appendix E) refers to the PIEE throughout.

Prior to the development of the PIEE, a SDS was produced (**Research Objective 3**), which provides the outline of the system in order to enable its development (**Research Objective 4**). The SDS contains the initial documentation for the system, including an overview of the system with a use case diagram, activity flow diagrams for all the key methods and a data dictionary for all the attributes. In addition, it identifies the key performance indicators for the system. The Universal Modelling Language (UML) class diagrams in the SDS conform to the UML 2.0 convention (Fowler, 2004) and were created using the VioletUML editor (2.0.1) – a freeware UML editor (<http://violet.sourceforge.net/>).

The SDS is based on a template (Appleton, 1994) that is founded on a number of standard texts and standards, including those of the Institute of Electrical and Electronics Engineers for Software Designs (IEEE, 2009) and Software Requirements (IEEE, 2011). The template was selected because it did not seek to assume or impose a particular software development methodology or paradigm, and because it emphasises content rather than format.

As stated in the previous chapter, the research for this and the preceding chapter formed the basis for two conference papers (Winning, 2014c, Winning, 2014a).

7.1 System Overview

Reserved words of the PIEE system (classes, attributes etc.) are formatted thus: **PIEEPoint**.

The PIEE is designed to facilitate aspects of pipeline design across the fields of pipeline engineering, environmental engineering and engineering design. Key features of the system discussed in this chapter include the following:

- **Pipeline hydraulics:** By including preliminary pipeline hydraulics within the system, it is possible for the pipeline engineer to assess the impact of route selection on the hydraulic design of the system. It also enables the hydraulic engineer to compare routes hydraulically and to determine the potential optimum combination of pipe size and compressor/pump station combinations for a specific route prior to detailed analysis.
- **Location class determination:** Currently the determination is based on the ASME B31.8 standard. This enables the engineer to determine accurately the code compliance requirements for the allocation of heavy wall pipe according to the population density for gas pipelines. Checks are available within the model to ensure compliance.
- **Estimated soil erosion loss:** This function enables the environmental engineer to perform a risk assessment for the potential soil erosion for the pipeline route. This enables the subsequent field investigation to be targeted to the areas of concern.
- **Automated production of drawings, reports and schedules:** The cost savings due to speed of production and the reduced burden on checking offset the design and maintenance of the PIEE system.

The overall use case diagram (Figure 2.2) shows the integrated approach and its application to the main stakeholders of the system.

The inputs into the PIEE start with engineering data (Basis of Design) in the design phase and progress through the construction phase to the input of operational data in the commissioning phase; this data flow is shown in Figure 7.1. Fundamental to the

development of the system is the realisation that different stages of the project present different challenges.

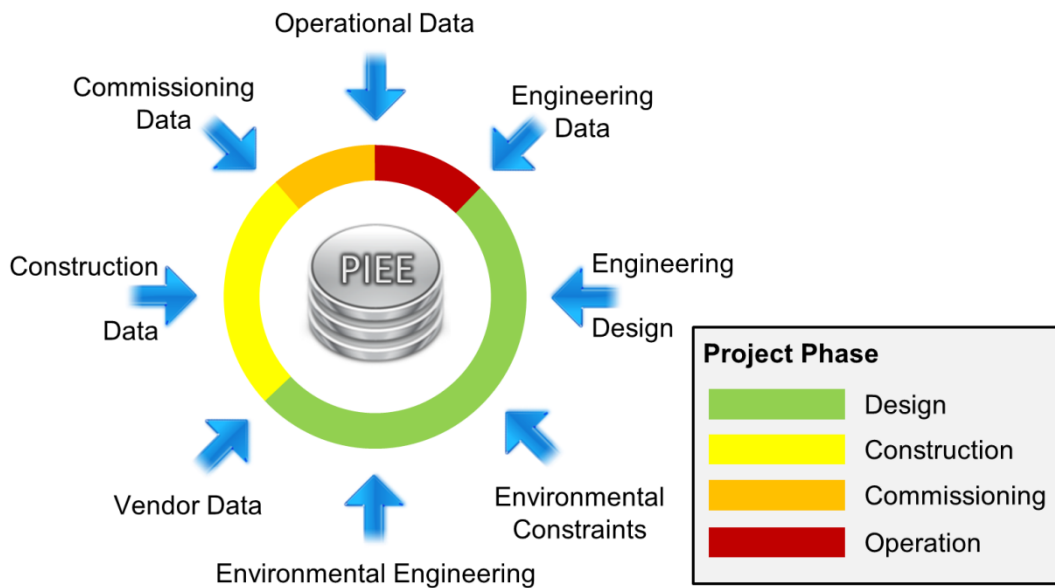


Figure 7.1 – PIEE Project Phases

The system is based on a data-centric model, which is accessible using a variety of systems. This enables the user rather than the system developers to determine the tools used to access and manipulate the model. It also recognises that the efficient design of pipeline projects requires a variety of different design tools.

One of the main requirements of the design phase of the project is to produce large numbers of alignment sheets and route maps for the entire route. With an alignment sheet typically covering 1km of pipeline, the number of drawings required for major projects is significant. The choice of engineering design software is based on a number of criteria, including:

- requirement to handle geospatial data
- ability to produce large volumes of complex design drawings
- preference and availability of trained users

In the current model, AutoCAD Civil 3D was selected as the engineering design geospatial software.

The modified PODS schema was made available to AutoCAD either by linking directly to the ArcSDE server or by storing the data within a single model drawing. The second option can be useful where the users' knowledge of database handling within the AutoCAD environment is a constraint, or for small projects in which it is wished to avoid incurring the

overheads and costs of ArcSDE. In this case, the tabular data is stored as extended entity data.

The interface for both CAD and GIS provides access to the additional PIEE functionality through a structured system of toolbars and menus – though this does not apply to the tools for the production of the alignment sheets, which are only accessible through the CAD system. Although it requires the recoding of the system to enable tools to be available through both systems, this recoding is fundamental to enabling the user to determine the software tools to use.

7.2 Constraints

The PIEE needs to function within the current hardware and software environment. The current systems are using the Microsoft Windows 7 operating system on high-end Dell workstations with 16Gb of RAM. The main engineering design tool is AutoCAD Civil 3D 2010. However, it must also be compatible with AutoCAD Civil 3D 2015.

The current engineering design team comprises designers with a range of skills, experience and ability and with previous exposure to the use of automated design solutions. Given the team's experience with AutoCAD, the system will be designed to present the user with a system that conforms to the design principles of AutoCAD in order to reduce the requirements for extensive training.

In addition, the code makes use of two libraries of functions – acLib, an internal suite of Visual LISP functions written by the author to support the development of the PIEE software, and DosLib, a freeware library developed by Robert McNeel Associates.

7.3 Requirements

The requirements for the system are summarised by category as follows:

- General:
 - QA/QC integrity of model data and processes
 - functional rather than software-centric design
 - allow the user to select toolsets based on preference for data creation
 - reduction in the number of interfaces
 - reduction in the cost and time to deliver the pipeline design

- Engineering:
 - the ability to perform engineering calculations within a GIS environment (pipeline hydraulics)
 - the ability to use GIS to perform geospatial engineering design (location class requirements)
 - version control of the route and associated attributes

- Environmental Engineering:
 - the ability to perform environmental engineering analysis based on remote sensed data

- Engineering Design:
 - automated production of key project deliverable design documents
 - use of templates to automate initial design
 - reduction in manual checking of deliverable documents

- GIS:
 - import and export of design, vendor and construction data
 - validation of the model through the automated production of model validation documents
 - web interface

- User Interface:
 - intuitive – does not replicate standard features
 - retains the standard look and feel of the native interface

7.4 System Design

The development of the PIEE is based on an object orientated programming (OOP) approach. Core feature classes are defined, with the ability for the user to define additional feature classes with attributes and methods inherited from the abstract classes. From defined abstract and feature classes, a data dictionary has been created. Finally, the methods for the classes identified in the UML class diagrams are listed, with the key methods outlined in UML activity flow diagrams.

7.4.1 Object Model and Classes

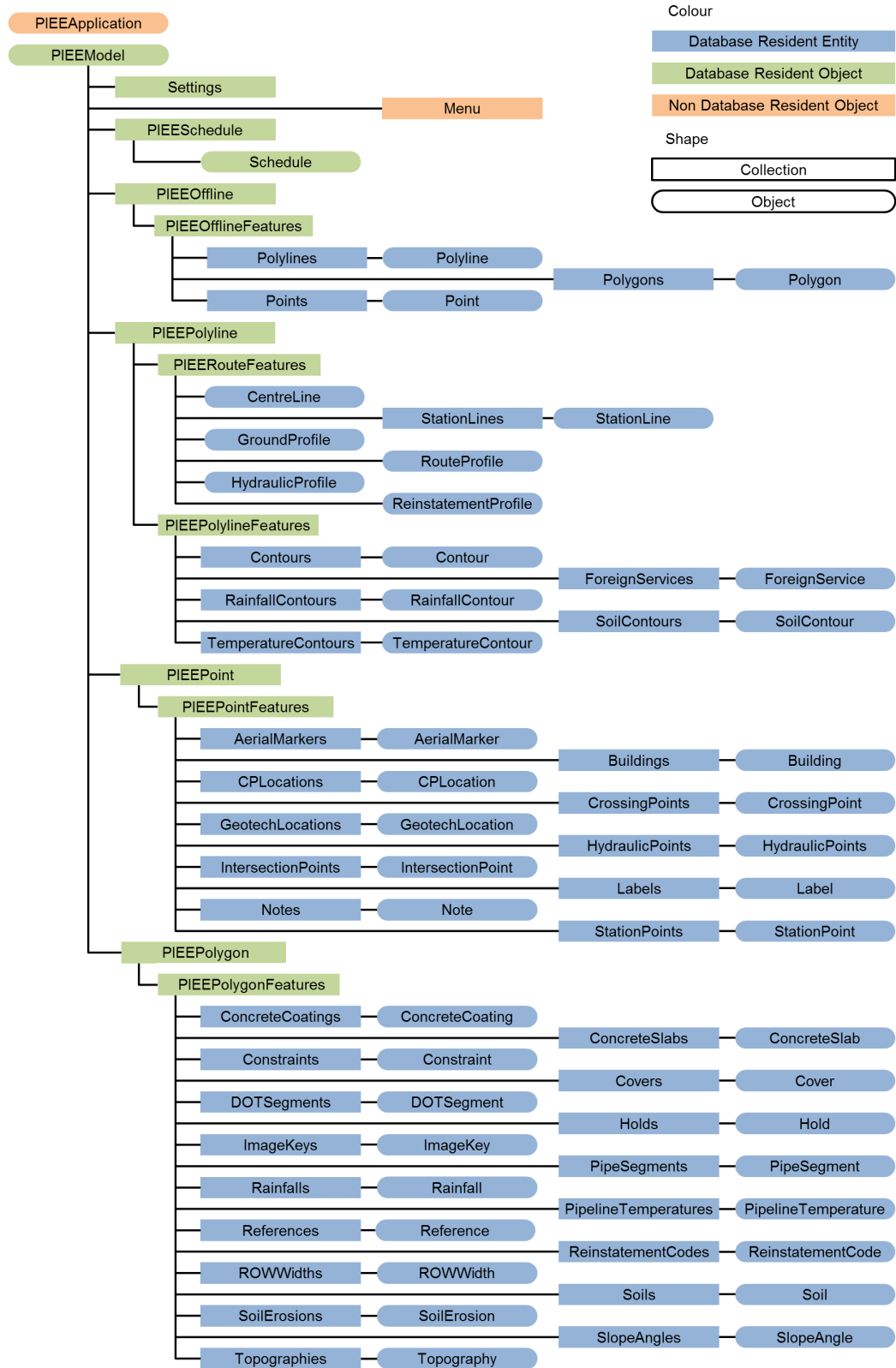


Figure 7.2 – PIEE Object Model

The PIEE object model has been designed to be very similar to the AutoCAD object model in order to facilitate the development and integration of the PIEE within the AutoCAD environment. The system comprises abstract and feature classes, which define the structure.

7.4.2 Abstract Classes

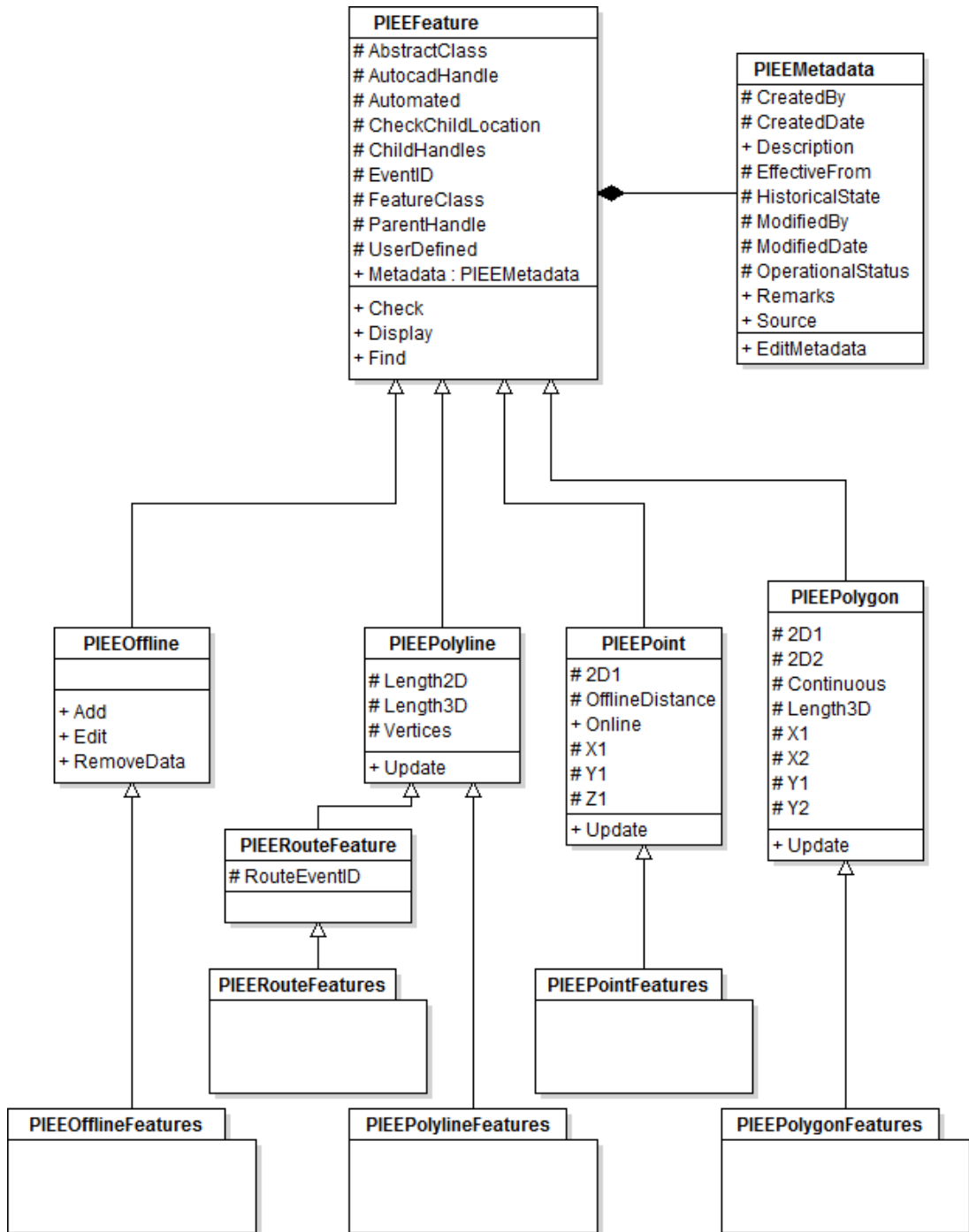


Figure 7.3 – PIEE Abstract Classes

The top-level abstract class is the **PIEEFeature** class, which provides all the common attributes and methods for the features. It is composed of the **PIEEMetadata** class, which provides the methods and attributes for the metadata associated with all PIEE features (Figure 7.3). Features within PIEE are further subdivided into five abstract classes.

The **PIEEOffline** class is used for all geometry that does not belong to another abstract class that is to be included in the PODS model export and provides the common methods and attributes for these features.

The **PIEEPolyline** abstract class supports all polyline²⁷ feature classes. The features that define the pipeline route geometry are based on the **PIEERouteFeature** abstract class. The **PIEEPoint** and **PIEEPolygon** abstract classes provide the methods and attributes for the point and polygon features respectively.

7.4.3 Feature Classes

7.4.3.1 PIEEModel and PIEESchedule

With the exception of the **PIEEModel** and **PIEESchedule** feature classes, all the feature classes are based on the abstract classes. These two feature classes have no inheritance or associated geometry, and reside in the model in tabular form, stored in AutoCAD dictionaries. They are shown in Figure 7.4 and Figure 7.5 respectively.

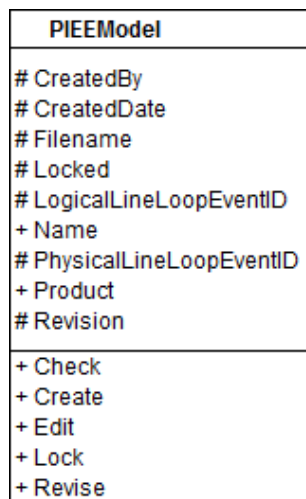


Figure 7.4 – PIEE Model Feature Class

²⁷ An AutoCAD entity with multiple vertices, used to define a linear feature in three planes.

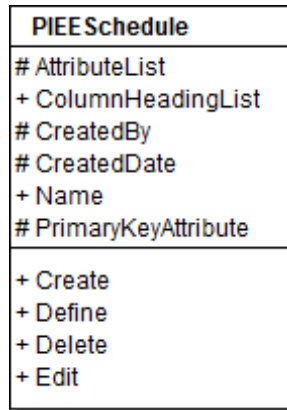


Figure 7.5 – PIEE Schedule Feature Class

7.4.3.2 PIEEOffline

Feature classes based on this abstract class are by geometry type (polygon, polyline and point). This is based on the ArcGIS shapefile format, which does not permit mixed geometry primitives in a single shapefile (Figure 7.6).

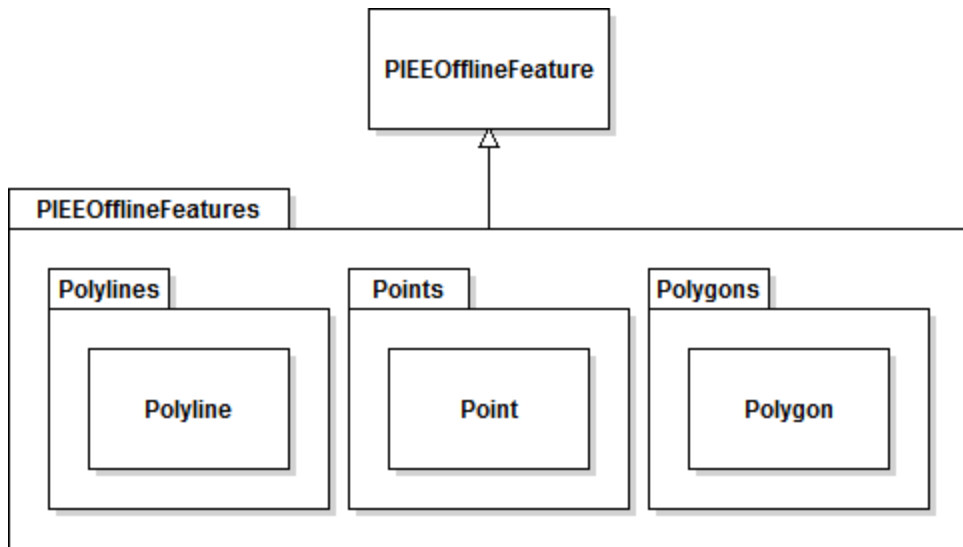


Figure 7.6 – PIEE Offline Feature Classes

7.4.3.3 PIEEPolyline

As previously discussed, a subset of these features inherits methods and attributes from the **PIEERouteFeature** abstract class. These features define the pipeline route (Figure 7.7).

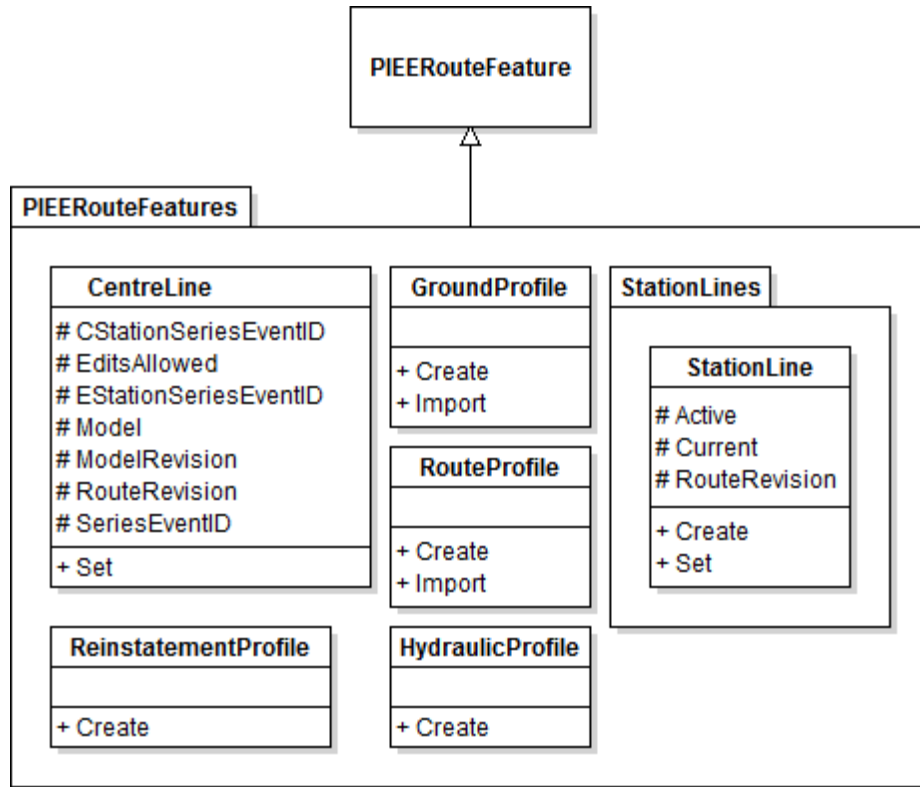


Figure 7.7 – PIEE Route Feature Classes

The feature classes based on this abstract class are as follows:

- **CentreLine**: This is the design 2D line and comprises straight-line segments. It is shown with all bends represented by intersection points.
- **StationLine**: This is a 2D polyline based on the centreline but with the bends represented according to radius and angle of the intersection points. This is used for generating the stationing or chainage values of the online features. All previously issued **StationLines** are retained in the model to enable the engineer to input or query data, based on historical stationing.

- **GroundProfile:** This is a 3D polyline based on the current **StationLine** with additional vertices added at the intersection of the **StationLine** and the **Contour** polylines.
- **RouteProfile:** This is a 3D polyline based on the **GroundProfile** and represents the top of pipe based on the depth of cover requirements.
- **ReinstatementProfile:** This is a 3D polyline based on the **GroundProfile**, which has been simplified to reduce the number of vertices. It is used to create the **SlopeAngles** feature class.
- **HydraulicProfile:** Similar to the **ReinstatementProfile**, it is a simplified 3D polyline representation of the **RouteProfile**. This is required because the proprietary hydraulic software is limited in the number of nodes that it can handle.

The remaining feature classes based on the **PIEEPolylineFeature** abstract class (Figure 7.8) are as follows:

- **Contours:** This class contains 2D polylines representing the surface model as contours. The contours are processed so that they all reside at an elevation of zero (the same elevation as the 2D route polylines) with their corresponding Z values stored as attributes.
- **TemperatureContours:** These 2D polylines are created in GIS and represent the ambient air temperature at a set interval. They are used to create the **PipelineTemperatures** feature class.
- **ForeignServices:** These 2D polylines represent foreign services (pipelines and cables).
- **RainfallContours:** These 2D polylines represent the rainfall erosivity (R) factor for the USLE based on the method discussed in Chapter 5.
- **SoilContours:** These 2D polylines represent the soil erodibility (K) factor for the USLE based on the method discussed in Chapter 5.

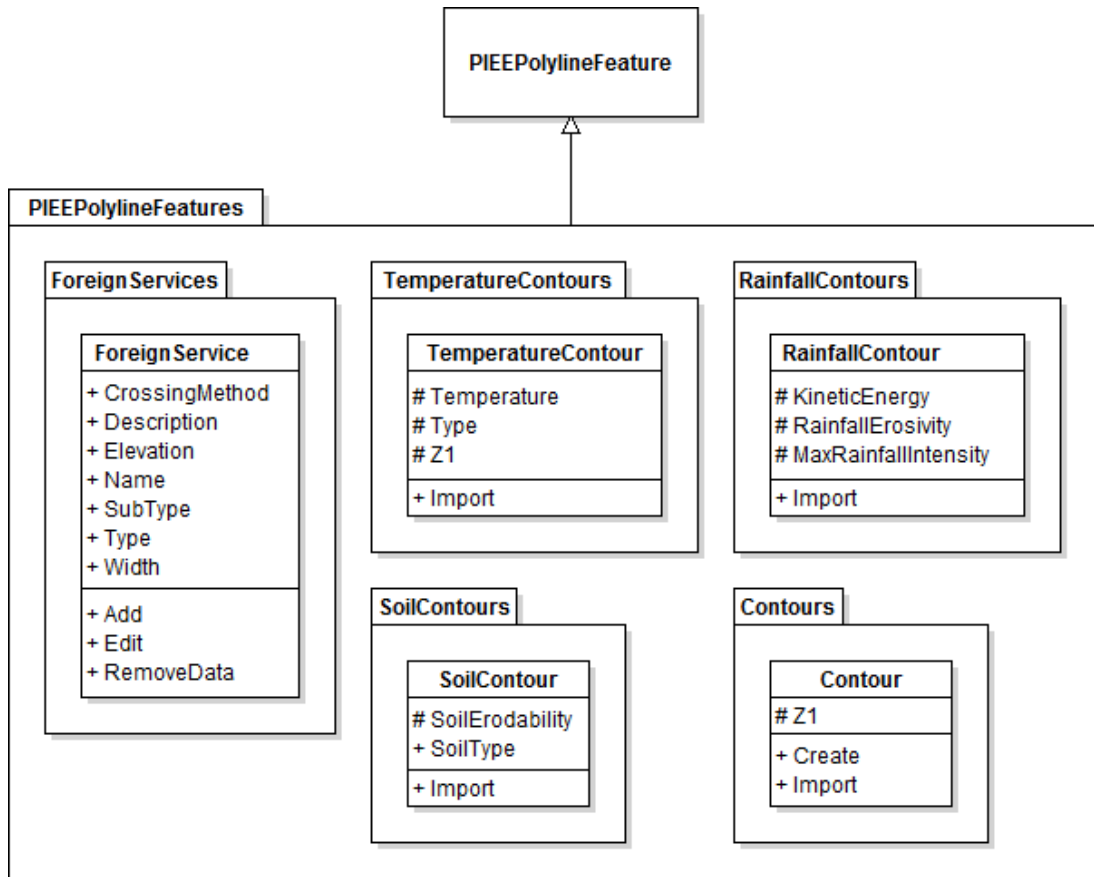


Figure 7.8 – PIEE Polyline Feature Classes

7.4.3.4 PIEEPoint

The **PIEEPoint** abstract class defines features that represent an online point event, which is a feature that has a start chainage and no length attribute (Figure 7.9). There are eleven defined point feature classes. These are:

- **AerialMarkers:** This feature class contains the location of the aerial markers on the pipeline route. It is populated automatically using a user-specified rule-based algorithm to locate the aerial markers at a nominal fixed interval and at significant changes of direction, with the ability to locate the markers at physical features within a specified distance of the calculated location.
- **Buildings:** The feature class contains the location of all buildings intended for human occupancy. This feature class is used to create the **DOTSegments** feature class that determines the minimum wall thickness for gas pipelines according to code requirements (location class).

- **StationPoints:** This feature class identifies the compressor/pump station locations as determined using the internal hydraulic analysis. The features are created through code.
- **HydraulicPoints:** This feature class stores all the intermediate calculation steps generated by the internal hydraulic analysis.
- **CrossingPoints:** This point feature class is created from the intersection of the current **StationLine** and the **PIEEPolyline ForeignService** feature class and the **PIEEPolygon Topographies** feature class. This represents all the physical and third party crossings on the pipeline and is tagged according to the user-specified format.
- **CPLocations:** This feature class identifies all the locations along the pipeline for which there is a CP requirement.
- **GeotechLocations:** This feature class stores the requirements for all the geotechnical soil investigation locations.
- **PipelineMarkers:** This feature class stores the location of the pipeline markers that are located at physical and third party crossings.
- **Labels:** This feature class is used to store all the labels and their position as required for the production of the drawings.
- **Notes:** This stores all the site-specific notes.
- **IntersectionPoints:** This feature class is populated based on the **CentreLine** geometry and stores all the changes in horizontal direction along the pipeline route.

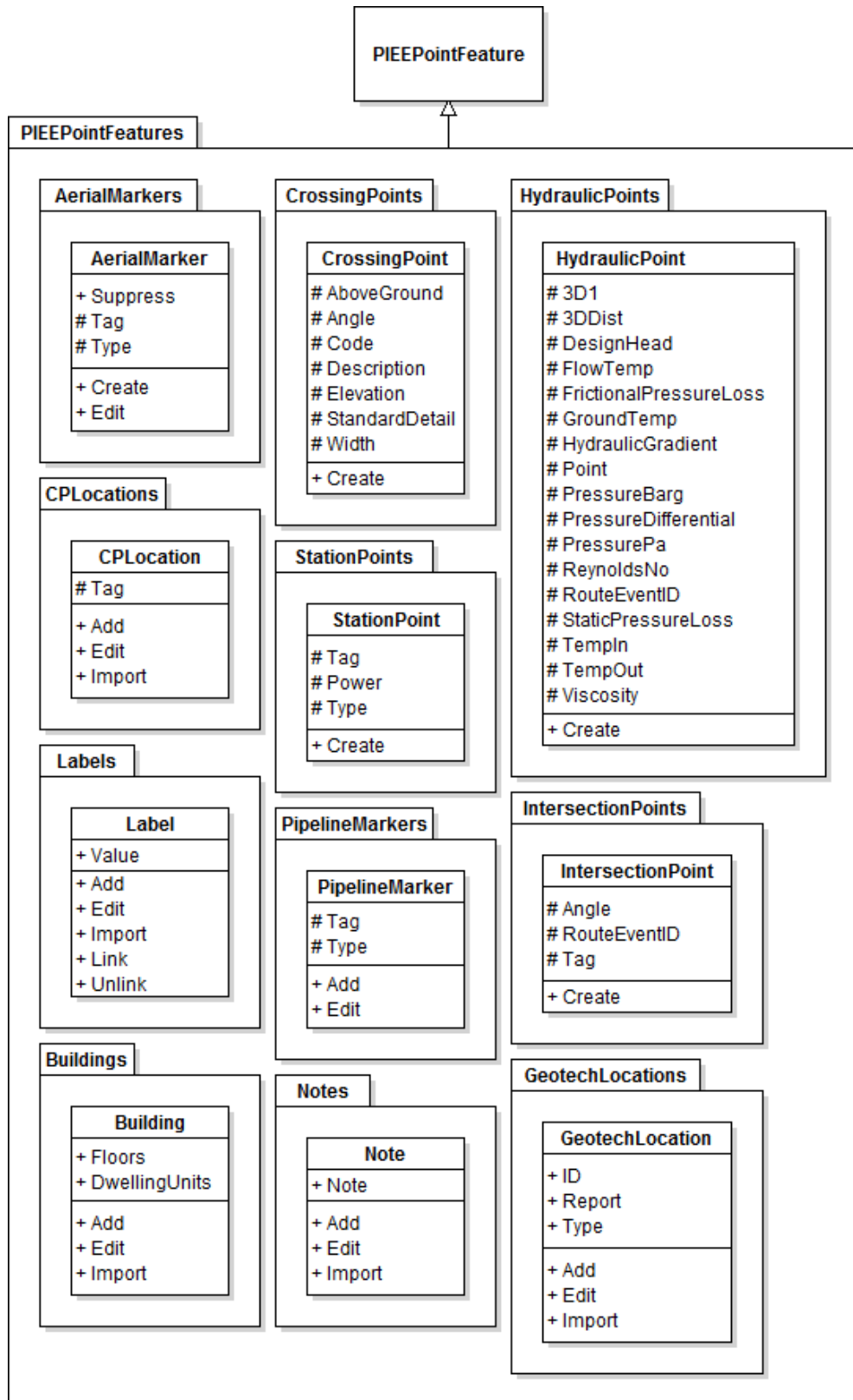


Figure 7.9 – PIEE Point Feature Classes

7.4.3.5 *PIEEPolygon*

The **PIEEPolygon** abstract class defines features that represent an online linear event, which has both a start and an end chainage on the **StationLine**. These features are discrete or continuous as identified by the **#Continuous** attribute. There are 10 continuous and seven discrete feature classes (Figure 7.10).

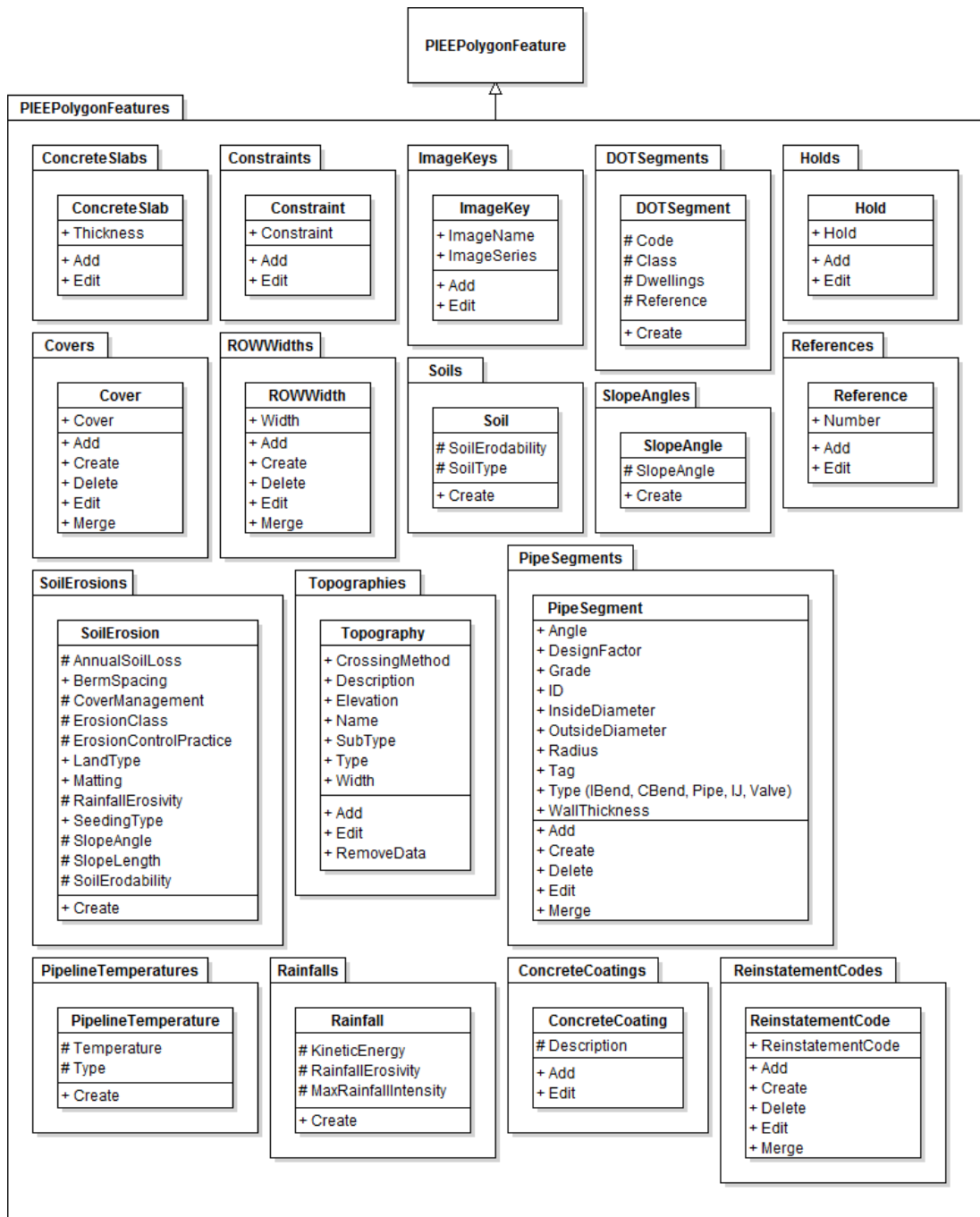


Figure 7.10 – PIEE Polygon Feature Classes

The continuous **PIEEPolygon** feature classes are as follows:

- **PipeSegments:** These polygons represent unique design segments of the pipeline. These include:
 - pipe (grade, diameter and wall thickness)
 - fittings (valves, tees, pig traps, induction bends)
 - field bends
- **DOTSegments:** These are created by the location class function and represent the minimum wall thickness requirements due to population density according to code requirements. These are only applicable for gas pipelines.
- **PipelineTemperatures:** These are created from the intersection of the **TemperatureContours** and the **StationLine** and are used to perform thermal hydraulic analysis within the model.
- **SlopeAngles:** These are created from the intersection of the **ReinstatementProfile** and the **StationLine** and are used to perform the SERA within the model.
- **ROWWidths:** This class contains the width of the RoW that the construction contractor has for the installation of the pipeline. This identifies additional land at crossings (land boxes) and reduced working widths in environmentally sensitive areas.
- **Covers:** This class is the minimum depth of cover to the top of pipe for the pipeline.
- **Soils:** This feature class contains the soil erodibility (*K*) factor based on the intersection of the **PIEECentreLine** and the **SoilContours** for the route.
- **SoilErosions:** This feature class contains the results of the estimation of the soil erosion risk discussed in Chapter 5 – as well as the intermediate calculations for the individual components of the USLE.

- **Rainfalls:** This feature class contains the rainfall erosivity (R) factor based on the intersection of the **PIEECentreLine** and the **RainfallContours** for the route.
- **ReinstatementCodes:** This defines the reinstatement requirements for the pipeline route. Although it is based on the **SoilErosions** feature class, it enables requirements to be aggregated to simplify the final reinstatement requirements.

The seven remaining discrete **PIEEPolygon** feature classes are the following:

- **ConcreteCoatings:** This is the extent of external concrete coating for mechanical protection or negative buoyancy for the pipeline.
- **ConcreteSlabs:** This is the location of pre-cast concrete slabs for the mechanical protection of the pipeline. These are usually installed at ditch and stream crossings to prevent damage from third party interference.
- **Constraints:** The location of environmental, construction or other constraints that need to be considered during the construction of the pipeline.
- **ImageKeys:** This class stores the boundary for raster image files used to support the use of scanned topographic mapping, satellite imagery or aerial photography as a background to the model. This is not a discrete dataset as imagery may overlap.
- **Topographies:** These physical or third party features have a width factor that the pipeline might cross. These typically include roads, railways and watercourses.
- **Holds:** This class identifies the extents of any engineering holds that are in place for specific sections of the pipeline. These are used during the design phase to identify areas that require additional information for the completion of the design.
- **References:** These are the extents of drawings that are relevant to sections of the pipeline and that are external to the model, such as drawings produced by other disciplines.

7.4.4 Data Types and Data Dictionary

A data dictionary is provided for all the attributes of the model (Appendix E). It provides the following information about the attribute:

- whether the attribute is a calculated value (not user-editable)
- a description for the attribute
- the methods that set the attribute
- its data type (Table 7.1)
- whether it is based on a domain list value

Domain lists are also provided for all the attributes that require them, tabulated in the format of domain name (feature class.method) and values (Appendix E).

Type	Description
GUID	Global Unique Identifier for the entity. 32 character string of hexadecimal numbers enclosed in braces (curly brackets).
Real	A real is a number containing a decimal point. Numbers between -1 and 1 must contain a leading zero. Real numbers are stored in double-precision floating-point format, providing at least 14 significant digits of precision.
Integer	Integers are whole numbers that do not contain a decimal point. AutoLISP integers are 32-bit signed numbers with values ranging from +2,147,483,647 to -2,147,483,648. (Note, however, that the getint function only accepts 16-bit numbers ranging from +32767 to -32768.)
String	A string is a group of characters surrounded by quotation marks. Within quoted strings the backslash (\) character allows control characters (or escape codes) to be included.
Boolean	T or NIL

Table 7.1 – PISE Data Types

7.4.5 Methods

The methods have been assigned function codes, which are used to link the code module and the activity flow diagrams, and which have been created for the main methods. These have been created primarily to assist in the coding of the modules, but also serve to provide an overview of the code. All the defined methods (Appendix E) identify the scope of the method, either public (P) or internal (I). Although internal methods are usually referred to as private methods, the use of the term internal has been used in the PISE to distinguish

between the prefix of the two method scopes. The internal methods are called from the public methods, whereas the public methods are made available to the user through the interface. In addition, all methods have a description and function code. The function code identifies the functional group that the method is a member of (engineering, routing, etc.), the scope, index and number. The index enables methods to be grouped, which in turn enables internal methods to be associated with their calling public methods. This is shown in Figure 7.11.

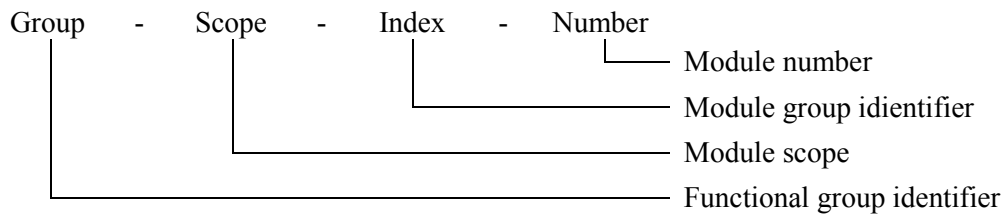


Figure 7.11 – Function Code Format

7.5 User Interface

The main user interface for model building and the creation of drawings and reports is the AutoCAD interface. A partial AutoCAD menu (PIEE.cui) has been created with tabs titled ‘PIEE Model’ and ‘PIEE Design’. The menu is supported by an AutoLISP file (PIEE.mnl) which performs the necessary function to initialise the PIEE system. Standard representations have been used where appropriate for common methods. The user interface comprises two ribbons defined in a partial AutoCAD menu (PIEE.cui), one for the model building functions and the other for the production of the drawings, schedules and reports

7.5.1 Modelling

The PIEE Model ribbon tab provides the user with access to all the main functions required to create and manage the model. The following figure shows a screen shot of the PIEE Model ribbon tab within the AutoCAD environment (Figure 7.12).

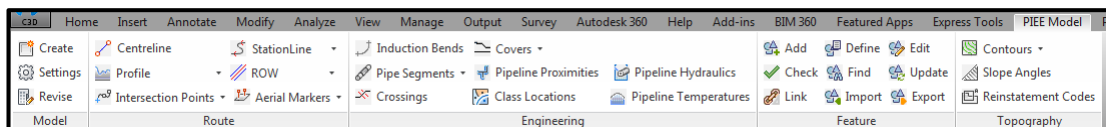


Figure 7.12 – PIEE AutoCAD Menu (PIEE Model Ribbon Tab)

The PIEE Model ribbon tab is further broken down into the following panels, grouping the controls by functional requirement:

Model Panel : contains the PIEE functions to create a new model, revise an existing model and edit model settings via the model settings dialog box. The model settings dialog box will also include a toggle to lock or unlock the model for editing (Figure 7.13).

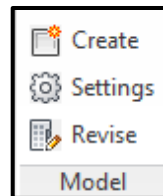


Figure 7.13 – Model Panel

Route Panel: Contains the PIEE functions related to routing features, including Centreline, StationLine, Profile, ROW, Intersection Points and Aerial Markers. (Figure 7.14).

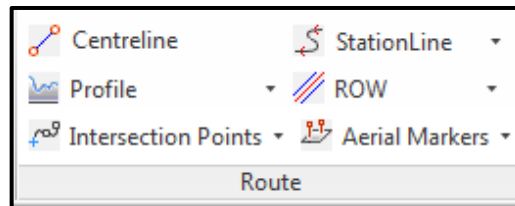


Figure 7.14 – Route Panel

Route Panel - StationLine Drop Down List: Contains the available methods for the StationLine feature, Create, Set and Update (Figure 7.15).

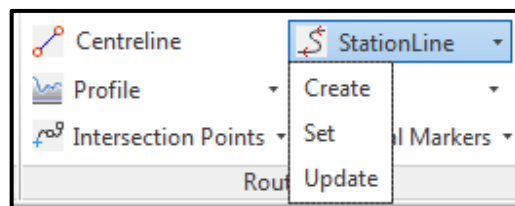


Figure 7.15 – Route Panel, StationLine Drop Down List

Route Panel - Profile Drop Down List: Contains the functions to create the Ground Profile, Route Profile, Hydraulic Profile and Reinstatement Profile (Figure 7.16).

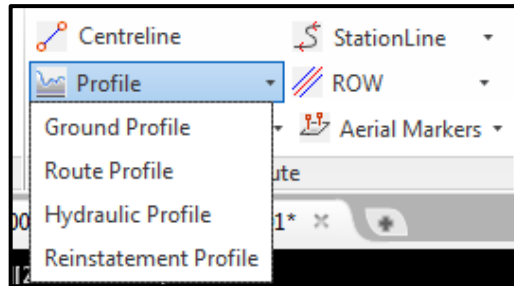


Figure 7.16 – Route Panel, Profile Drop Down List

Route Panel - ROW Drop Down List: Contains the available methods for the ROW feature, Add, Create, Delete and Edit (Figure 7.17).

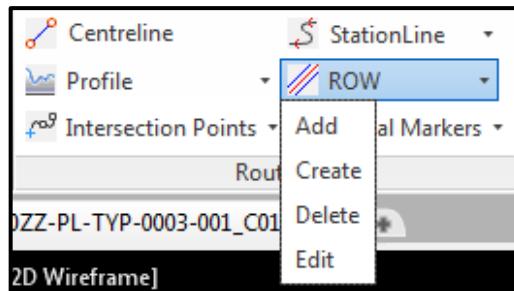


Figure 7.17 – Route Panel, ROW Drop Down List

Route Panel – Intersection Points Drop Down List: Contains the available methods for the Intersection Point feature, Create, Edit and Update (Figure 7.18).

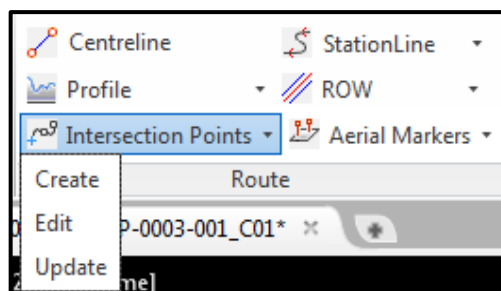


Figure 7.18 – Route Panel, Intersection Points Drop Down List

Route Panel – Aerial Markers Drop Down List: Contains the available methods for the Aerial Marker feature, Create, Edit and Update (Figure 7.19).

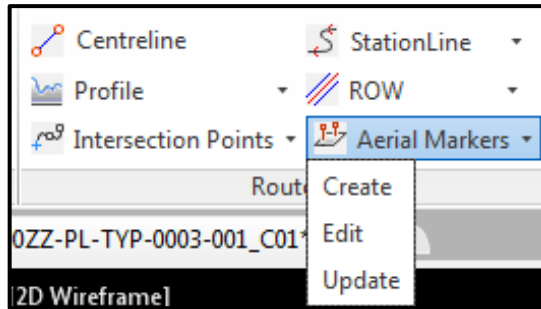


Figure 7.19 – Route Panel, Aerial Markers Drop Down List

Engineering Panel: Contains PIIIE functions related to engineering features including Induction Bends, Pipe Segments, Crossings, Covers, Pipeline Proximities, Class Locations, Pipeline Hydraulics and Pipeline Temperatures (Figure 7.20).

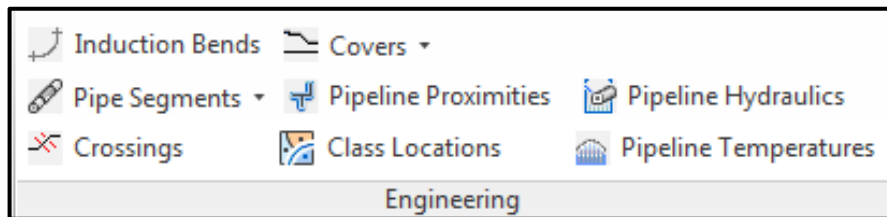


Figure 7.20 – Engineering Panel

Engineering Panel – Pipe Segments Drop Down List: Contains available methods for the Pipe Segment feature, Add, Create, Delete and Edit (Figure 7.21).

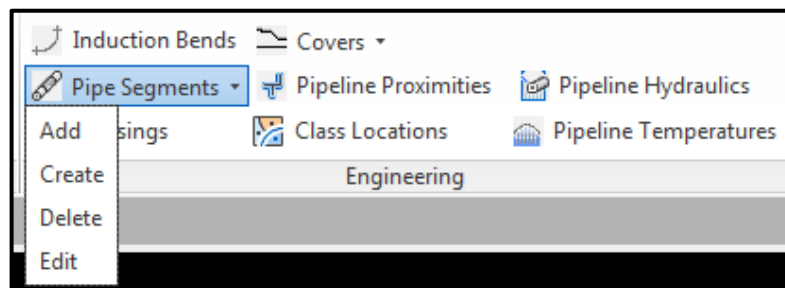


Figure 7.21 – Engineering Panel, Pipe Segments Drop Down List

Engineering Panel – Covers Drop Down List: Contains available methods for the Cover feature, Add, Create, Delete and Edit (Figure 7.22).

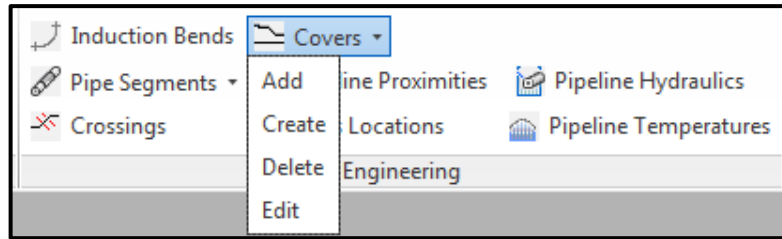


Figure 7.22 – Engineering Panel, Covers Drop Down List

Feature Panel: Contains PIEE feature methods. Each button will open a dialog box that will present the user with a list of features that the method applies to, including Add, Define, Edit, Check, Find, Update, Link, Import and Export (Figure 7.23).

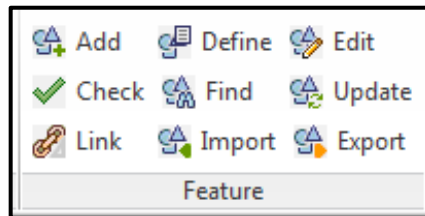


Figure 7.23 – Feature Panel

Topography Panel: Contains PIEE functions related to topographical features and includes Contours, Slope Angles and Reinstatement Codes (Figure 7.24).

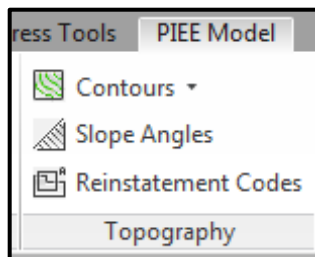


Figure 7.24 – Topography Panel

Topography Panel: Contours Drop Down List: Contains available methods for the Contour feature, Create and Import (Figure 7.25).

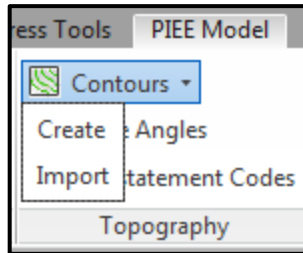


Figure 7.25 – Topography Panel, Contours Drop Down List

7.5.2 Design and Reporting

Similar to the modelling interface, the design and reporting interface provides access to the controls for creating, managing and generating drawings and reports. Figure 7.26 shows a screen shot of the PIEE Design menu within the AutoCAD environment:

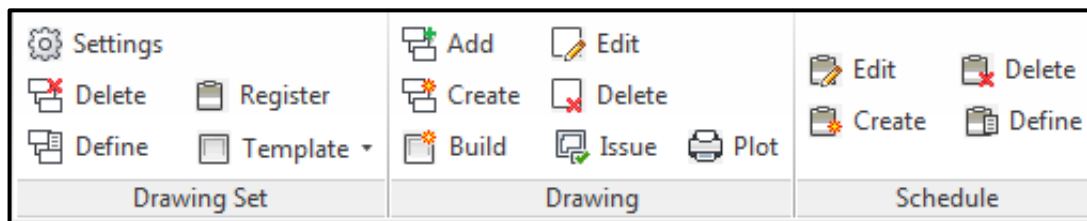


Figure 7.26 – PIEE AutoCAD Menu (PIEE Design Ribbon Tab)

Drawing Set Panel: Contains PIEE functions related to Drawing Sets and includes Define, Delete, Settings, Template and Register (Figure 7.26).

Drawing Set Panel: Template Drop Down List : Contains available methods for Drawing Set Templates, Create and Edit (Figure 7.27).

Drawing Panel: Contains PIEE functions related to Drawings, and includes Build, Create, Add, Issue, Delete, Edit and Plot (Figure 7.26).

Schedule Panel: Contains PIEE functions related to Schedules and includes Create, Edit, Define and Delete (Figure 7.26).

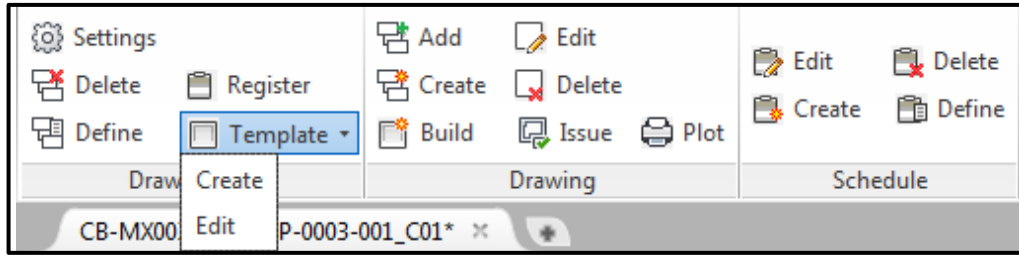


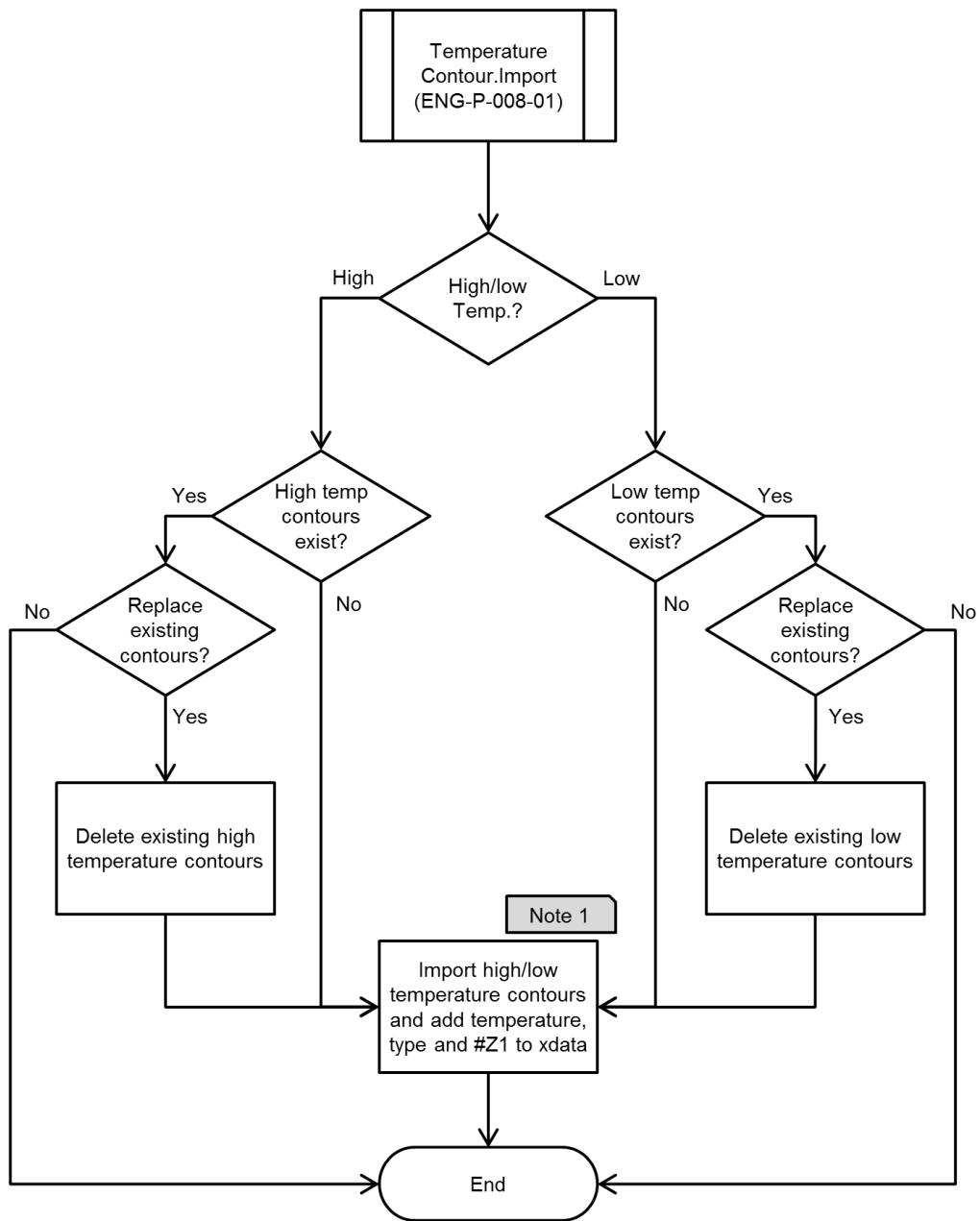
Figure 7.27 – Drawing Set Panel Template Drop Down List

7.6 Core Components

A UML activity diagram is a useful way of visually representing the logic flow for a complex use case (Wiegers and Beatty, 2013: 154); these are sometimes also referred to as flowcharts (Patton, 2006: 27). This approach has been adopted in the SDS, with extensive use of flowcharts based on the UML activity diagram concept. These are repeated in this chapter, when they relate to the areas researched in Chapter 4, 5 and 6.

7.6.1 Hydraulic Analysis

This section provides an overview of the preliminary hydraulic modelling within the PIEE based on the research presented in Chapter 4 Section 4.2. Using WMO data, the high and low ambient air temperatures are obtained for the weather stations in the area of the proposed pipeline route. Using this data combined with the weather station elevation, a choropleth map for both the high and low temperatures are created in GIS, as are vector contours. These are imported using the **TemperatureContour.Import** method (Figure 7.28).



Notes
1. Temperature contours calculated and exported from GIS.

Figure 7.28 – TemperatureContour.Import (ENG-P-008-01) Flowchart

For any given route, the **PipelineTemperatures** polygon feature class is created from the intersection of the **CentreLine** polyline route feature and the **TemperatureContours** polyline feature (Figure 7.29).

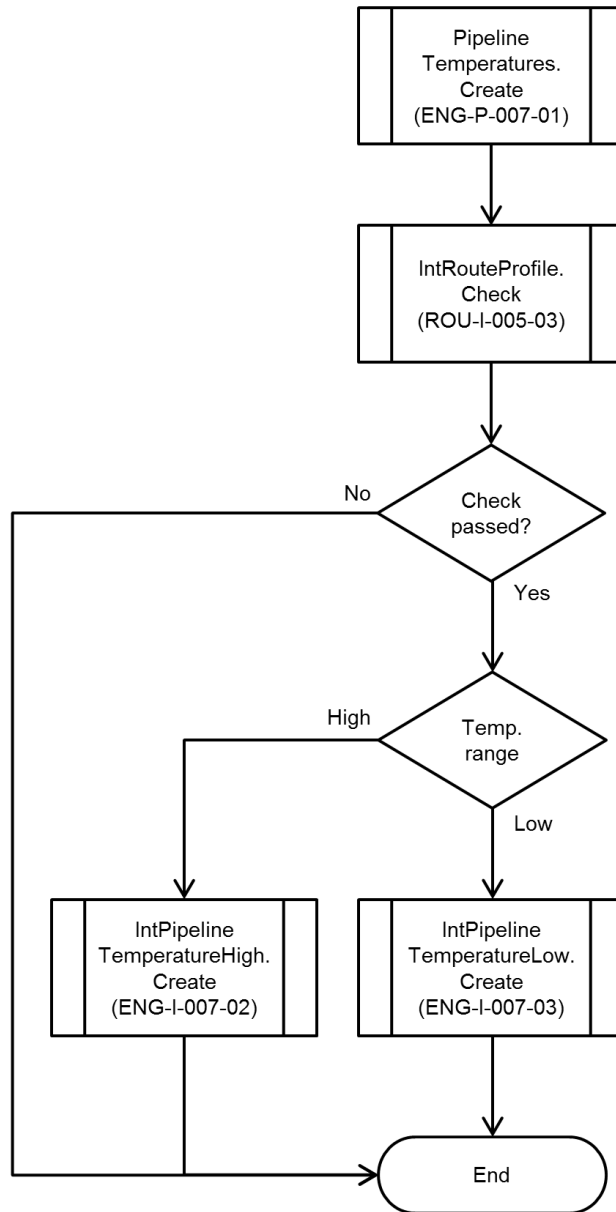


Figure 7.29 – PipelineTemperature.Create (ENG-P-007-01) Flowchart

The **PipelineHydraulics.Create** method (Figure 7.30) performs all the high-level checks to ensure that the required feature classes exist, prior to calling the **IntPipelineHydraulics.Calculate** method.

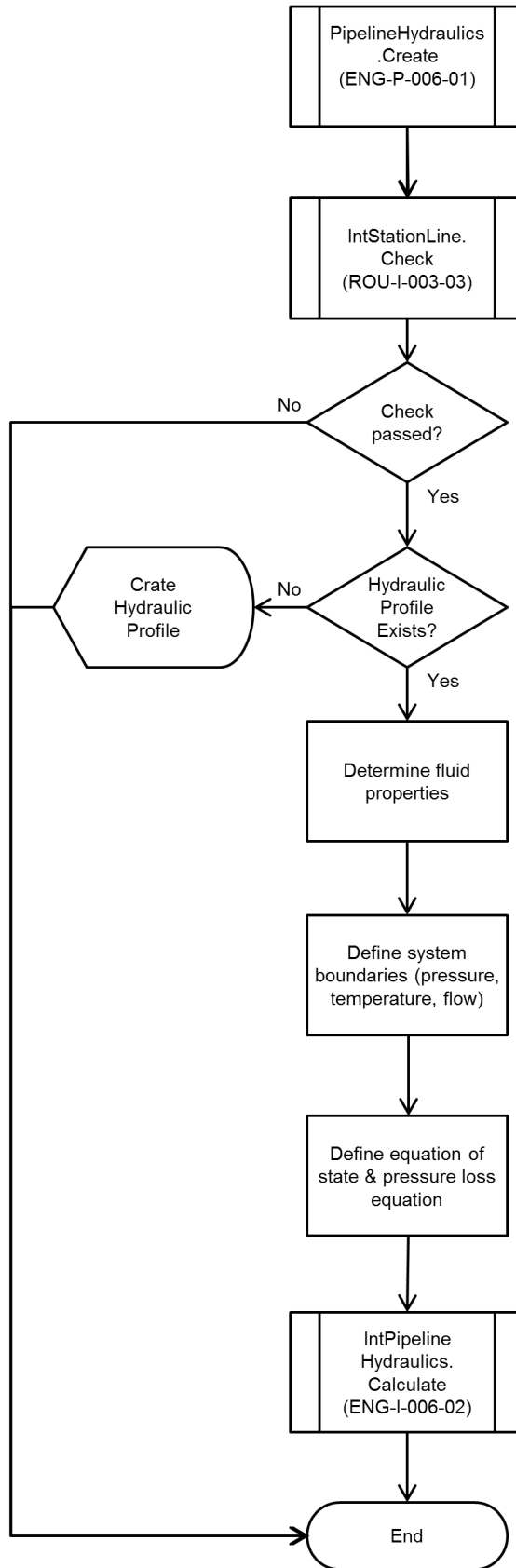


Figure 7.30 – PipelineHydraulics.Create (ENG-P-006-01) Flowchart

The **IntPipelineHydraulics.Calculate** method (Figure 7.31) creates the **HydraulicPoints** and **StationPoints** point feature classes based on the **HydraulicProfile**, which is a **PIEERouteFeature** class.

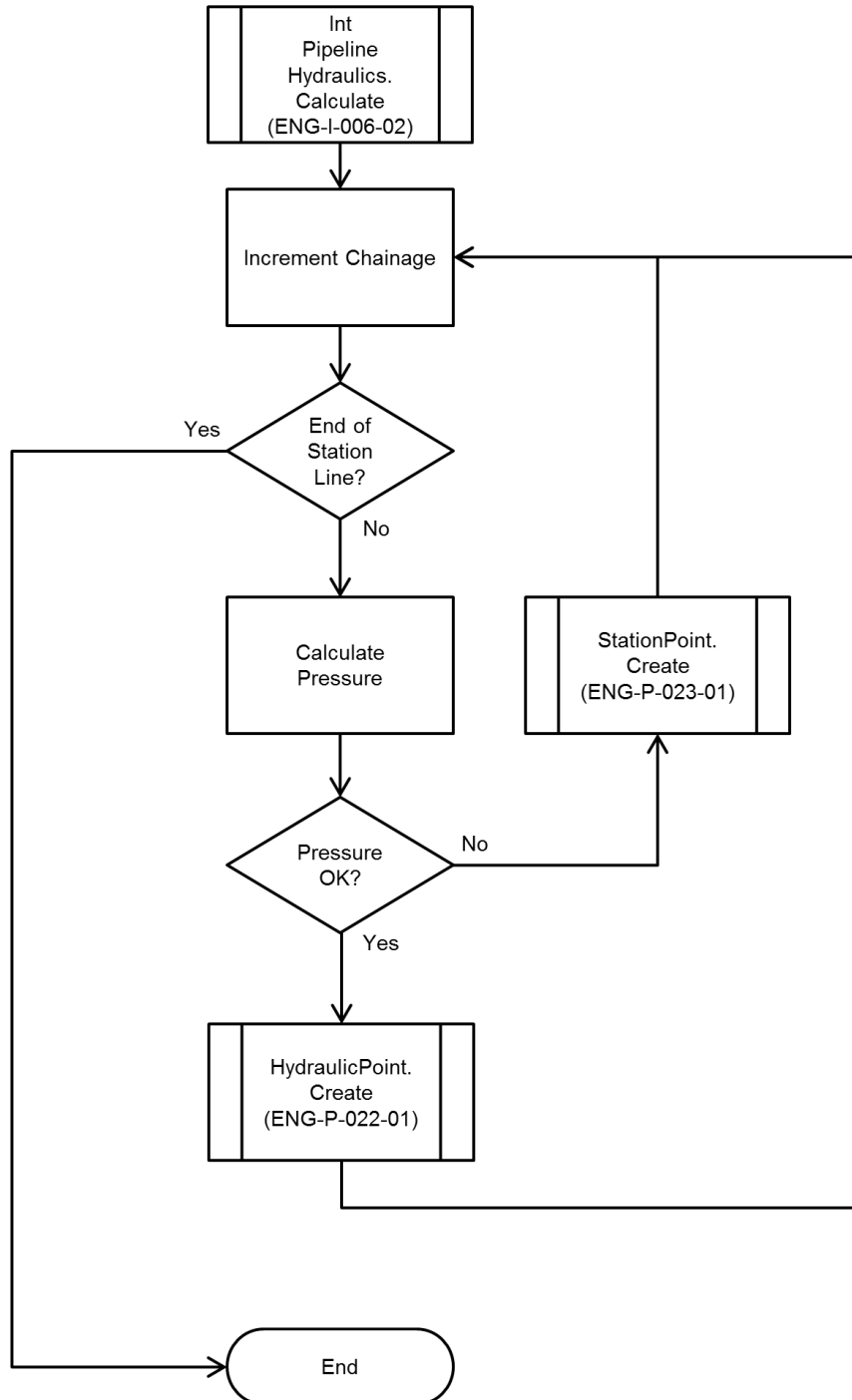


Figure 7.31 – IntPipelineHydraulics.Calculate (ENG-I-006-02) Flowchart

From the start of the StationLine and at intervals as specified in the project settings, the pressure is determined at each point. If the pressure is greater than the inlet pressure requirements a HydraulicPoint is created. The details for creating these features are:

1. The **PIEEPPoint.#2D1** attribute is set to the 2D chainage of the point from the current **StationLine**.
2. The **PIEEPPoint.#Z1** attribute is set to the elevation of the point from the **HydraulicProfile** polyline feature.
3. The 3D (slope) distance from the preceding point is set to the **HydraulicPoint.#3DDist** attribute. It is set to zero for the first point.
4. The 3D chainage of the point from the current **StationLine** is set to the **HydraulicPoint.#3D1** attribute. It is set to zero for the first point.
5. The design head (**HydraulicPoint.#DesignHead**) is calculated by dividing the operating pressure in Pa by the fluid density multiplied by gravity and adding the elevation (**PIEEPPoint.#Z1**) of the current point.
6. The ground temperature (**HydraulicPoint.#GroundTemp**) is set to the temperature as determined by the intersection of the **StationLine** and the **PipelineTemperature** feature class.
7. The input temperature (**HydraulicPoint.#TempIn**) attribute is set to the previous **HydraulicPoint.#TempOut** value. For the first point this value is set to zero.
8. For the first point the output temperature (**HydraulicPoint.#TempOut**) attribute is set to the inlet temperature. For subsequent points the following calculations are used. The Logarithmic Mean Temperature Difference (LMTD) is determined using

$$T_m - T_s = \frac{(T_{p1} - T_s) - (T_{p2} - T_s)}{\text{Log}_e \left[\frac{(T_{p1} - T_s)}{(T_{p2} - T_s)} \right]} \quad (\text{Eq. 7.1})$$

where

- T_m = Logarithmic mean temperature of pipe segment (°C)
- T_{p1} = Temperature of liquid entering pipe segment (°C)
- T_{p2} = Temperature of liquid leaving pipe segment (°C)
- T_s = Sink temperature, soil or surrounding medium (°C)

Equation 7.1 LMTD (Menon, 2004: 176 Eq 9.7)

The Logarithmic Mean Temperature Difference is then used in the following equations to determine the heat transfer for buried pipelines.

$$H_b = \frac{6.28(L_{pipe})(T_m - T_{soil})}{(Parm1 + Parm2)} \quad (Eq. 7.2)$$

where

- H_b = Heat transfer (W)
- T_m = Logarithmic mean temperature of pipe segment (°C)
- T_{soil} = Ambient soil temperature (°C)
- L_{pipe} = Length of pipe segment (m)

Equation 7.2 Heat Transfer 1 (Menon, 2004: 178 Eq 9.15)

$$Parm1 = \left(\frac{1}{K_{ins}} \right) \log_e \left(\frac{R_i}{R_p} \right) \quad (Eq. 7.3)$$

where

- R_i = Pipe insulation outer radius (mm)
- R_p = Pipe outer wall radius (mm)
- K_{ins} = Thermal conductivity of insulation (W m⁻¹ °C⁻¹)

Equation 7.3 Heat Transfer 2 (Menon, 2004: 178 Eq 9.16)

$$Parm2 = \left(\frac{1}{K_{ins}} \right) \ln \left[\frac{2D_{cov}}{od} + \left(\left(\frac{2D_{cov}}{od} \right)^2 - 1 \right)^{\frac{1}{2}} \right] \quad (Eq. 7.4)$$

where

- K_{ins} = Thermal conductivity of insulation (W m⁻¹ °C⁻¹)
- D_{cov} = Depth of cover to the pipe centreline (mm)
- od = Outside diameter (mm)

Equation 7.4 Heat Transfer 3 (Menon, 2004: 178 Eq 9.17)

9. The flow temperature is set to the mean of the inlet and outlet temperatures (**HydraulicPoint.#TempIn** and **HydraulicPoint.#TempOut**). For the first point, it is set to the specified inlet temperature.
10. The viscosity (**HydraulicPoint.#Viscosity**) attribute is calculated taking account of the variation due to the temperature with the following calculations. The American Society for Testing and Materials (ASTM) method of calculating the variation of the viscosity with relationship to the temperature has been used.

$$\log \log(Z) = A - B \times \log(T) \quad (\text{Eq. 7.5})$$

where

Z is dependent on the viscosity of the liquid ν

ν = Viscosity of the liquid (cSt)

T = Absolute temperature (K)

A and B are constants that depend on the specific liquid

Equation 7.5 ASTM 1 (Menon, 2004: 19 Eq 2.15)

The variable Z is defined as:

$$Z = (\nu + 0.7 + C - D) \quad (\text{Eq. 7.6})$$

where

$$C = \exp[-1.14883 - 2.65868(\nu)] \quad (\text{Menon, 2004: 19 Eq 2.17})$$

$$D = \exp[-0.0038138 - 12.5645(\nu)] \quad (\text{Menon, 2004: 19 Eq 2.18})$$

Z is dependent on the viscosity of the liquid ν

ν = Viscosity of the liquid (cSt)

Equation 7.6 ASTM 2 (Menon, 2004: 19 Eq 2.16)

Given two sets of temperature viscosity values (T_1, ν_1) and (T_2, ν_2) the values for C , D and Z can be calculated from Equation 7.6. Substituting the pairs (T_1, Z_1) and (T_2, Z_2) into Equation 7.5 gives:

$$\log \log(Z_1) = A - B \times \log(T_1)$$

$$\log \log(Z_2) = A - B \times \log(T_2)$$

From these equations the two unknown constants A and B can be calculated.

11. The Reynolds number (**HydraulicPoint.#ReynoldsNo**) is calculated using the viscosity in cP by multiplying the density, fluid velocity and the pipe ID and dividing by the viscosity divided by 1000.
12. The frictional pressure loss (**HydraulicPoint.#FrictionalPressureLoss**) is set to zero for the first point. For subsequent points, the Darcy friction factor is calculated using the improved equation (Equation 4.6) proposed in Chapter 4, Section 4.2. This is then used in the following equation to calculate the frictional head loss.

$$h = f_d \left(\frac{L_{pipe}}{D} \right) \left(\frac{v_{mean}^2}{2g} \right) \quad (Eq. 7.7)$$

where

- h = Head (m)
- f_d = Darcy or D'arcy-Weisbach friction factor (Dimensionless)
- L_{pipe} = Length of pipe segment (m)
- D = Pipe internal diameter (m)
- v_{mean} = Average liquid velocity (m/s)
- g = Acceleration due to gravity (m/s^2)

Equation 7.7 Frictional Head Loss (Menon, 2004: 47 Eq 3.26)

13. The static pressure loss (**HydraulicPoint.#StaticPressureLoss**) for the first point is set to zero. For all other points it is calculated by subtracting the current elevation from the previous elevation and multiplying by the density and gravity.
14. The differential pressure (**HydraulicPoint.#PressureDifferential**) is the summation of the frictional (**HydraulicPoint.# FrictionalPressureLoss**) and static pressure (**HydraulicPoint.#StaticPressureLoss**) losses.
15. The pressure (**HydraulicPoint.#PressurePa**) is calculated by subtracting the pressure differential (**HydraulicPoint.#PressureDifferential**) from the pressure (**HydraulicPoint.#PressurePa**) attribute of the previous point. For the first point, this is set to the specified operating pressure.

16. The attribute **HydraulicPoint.#PressureBarg** is the pressure expressed in barg of the pressure stored in the (**HydraulicPoint.#PressurePa**) attribute, which is expressed in Pascals.
17. The **HydraulicPoint.#HydraulicGradient** attribute is calculated by adding the elevation (**PIEEPPoint.#Z1**) to the pressure (**HydraulicPoint.#PressurePa**) in pascals divided by the density and multiplied by gravity.

Where the pressure falls below the input pressure requirements, a **StationPoint** is created at the preceding **HydraulicPoint**. The power requirement is calculated using Equation 7.8 for pump stations and Equation 7.9 for compressor stations.

$$P_{pump} = \frac{Q_{pump} H_{pump} Sg}{367.46(E_{pump})} \quad (Eq. 7.8)$$

where

P_{pump} = Pump power (kW)

Q_{pump} = Pump flow rate (m³/hr)

H_{pump} = Pump head (m)

E_{pump} = Pump efficiency, decimal value less than 1 (dimensionless)

Sg = Liquid specific gravity (dimensionless)

Equation 7.8 Pump Power (Menon, 2004: 129 Eq 7.2)

$$Power \text{ kW} = 4.0639 \left(\frac{\gamma}{\gamma - 1} \right) Q_{gas} T_1 \left(\frac{Z_1 + Z_2}{2} \right) \left(\frac{1}{\eta_a} \right) \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \quad (Eq. 7.9)$$

where

- γ = Ratio of specific heats of gas (dimensionless)
- Q_{gas} = Gas flow rate (Mm³/day)
- T_1 = Suction temperature of gas (K)
- P_1 = Suction pressure of gas (kPa)
- P_2 = Discharge pressure of gas (kPa)
- Z_1 = Compressibility of gas at suction conditions (dimensionless)
- Z_2 = Compressibility of gas at discharge conditions (dimensionless)
- η_a = Compressor adiabatic (isentropic) efficiency, decimal value (dimensionless)

Equation 7.9 Compressor Power (Menon, 2005: 154 Eq 4.16)

In addition, the temperature is modified, accounting for the rise in the liquid temperature due to pump inefficiency (Equation 7.10) or the adiabatic temperature rise for compression (Equation 7.11).

$$\Delta T = \left(\frac{H_{pump}}{0.05670340543 C_p} \right) \left(\frac{100}{E_{pump} - 1} \right) \quad (Eq. 7.10)$$

where

- ΔT = Temperature rise (°C)
- H_{pump} = Pump head (m)
- C_p = Specific heat capacity of the liquid (J kg⁻¹ K⁻¹)
- E_{pump} = Pump efficiency, decimal value less than 1 (dimensionless)

Equation 7.10 Temperature Rise Due to Pump Inefficiency (Menon, 2004: 181 Eq 9.32)

$$\Delta T = T_1 \left(\frac{Z_1}{Z_2} \right) \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - T_1 \quad (\text{Eq. 7.11})$$

where

- ΔT = Temperature rise (°C)
- γ = Ratio of specific heats of gas (dimensionless)
- T_1 = Suction temperature of gas (K)
- P_1 = Suction pressure of gas (kPa)
- P_2 = Discharge pressure of gas (kPa)
- Z_1 = Compressibility of gas at suction conditions (dimensionless)
- Z_2 = Compressibility of gas at discharge conditions (dimensionless)

Equation 7.11 Adiabatic Temperature Rise (Menon, 2005: 155 Eq 4.21)

7.6.2 Location Class

This module determines the location class for gas pipelines in accordance with the ASME B31.8 code requirements. An extract of this standard is attached in Appendix C). This sets out the minimum design factor requirements for the pipeline based on the static and temporal population criteria within the PIR of a pipeline. This sets out the minimum wall thickness requirements. While the wall thickness may be increased for engineering requirements, the engineer must ensure that the wall thickness always meets or exceeds these requirements. This is determined using two modules. The first, initiated by the user (ENG-P-004-01), determines the requirements based on population density and the second (ENG-I-004-02), called internally by the first module, determines the requirements based on the crossing of roads and railways, and the requirements due to pipe assemblies and compressor station proximity.

An initial check is performed to ensure that the **StationLine** and the **Buildings** features are present; if not, the module informs the user and finishes. Otherwise, existing **DOTSegment** features are deleted if present, and the PIR calculated based on ASME B31.8S 3.2. Using a buffer with a length of 1610m (one mile) and a width of 202m (1/8th of a mile) as required by the code, the initial requirements due to population density are determined. This buffer is re-created at 100m intervals along the pipeline route to determine the random one-mile length with the greatest number of properties. The number of properties is either based on a count of the number of **Building** point features within the buffer, or the number of properties

associated with each **Building** point if this has been defined. If the number of properties exceeds forty-six, a further check is performed to determine if any of the **Building** point features have been identified as multi-storey buildings. Where this is the case, the location class is set to 4, otherwise it is set to 3. If the property count is less than or equal to forty-six, then consideration is given to the concentration of people (ASME B31.8 840.3 - Appendix C) within the section. If this criterion is met, then it is defined as location class 3. Otherwise, the location class is set to 2 if the number of properties exceeds eleven or 1 if it does not.

The geospatial limits of the section are then determined from the **Building** points closest to the start and the end of the section, ensuring that there is 202m from these **Building** point features. The section is therefore increased or decreased from the one-mile length as required by the proximity of the **Building** points to the start and end of the random one-mile section. The chainages for the start and end of this defined section are then stored in memory so that this section of the route is not re-evaluated. This is then repeated until the entire route has been classified. This is shown in Figure 7.32.

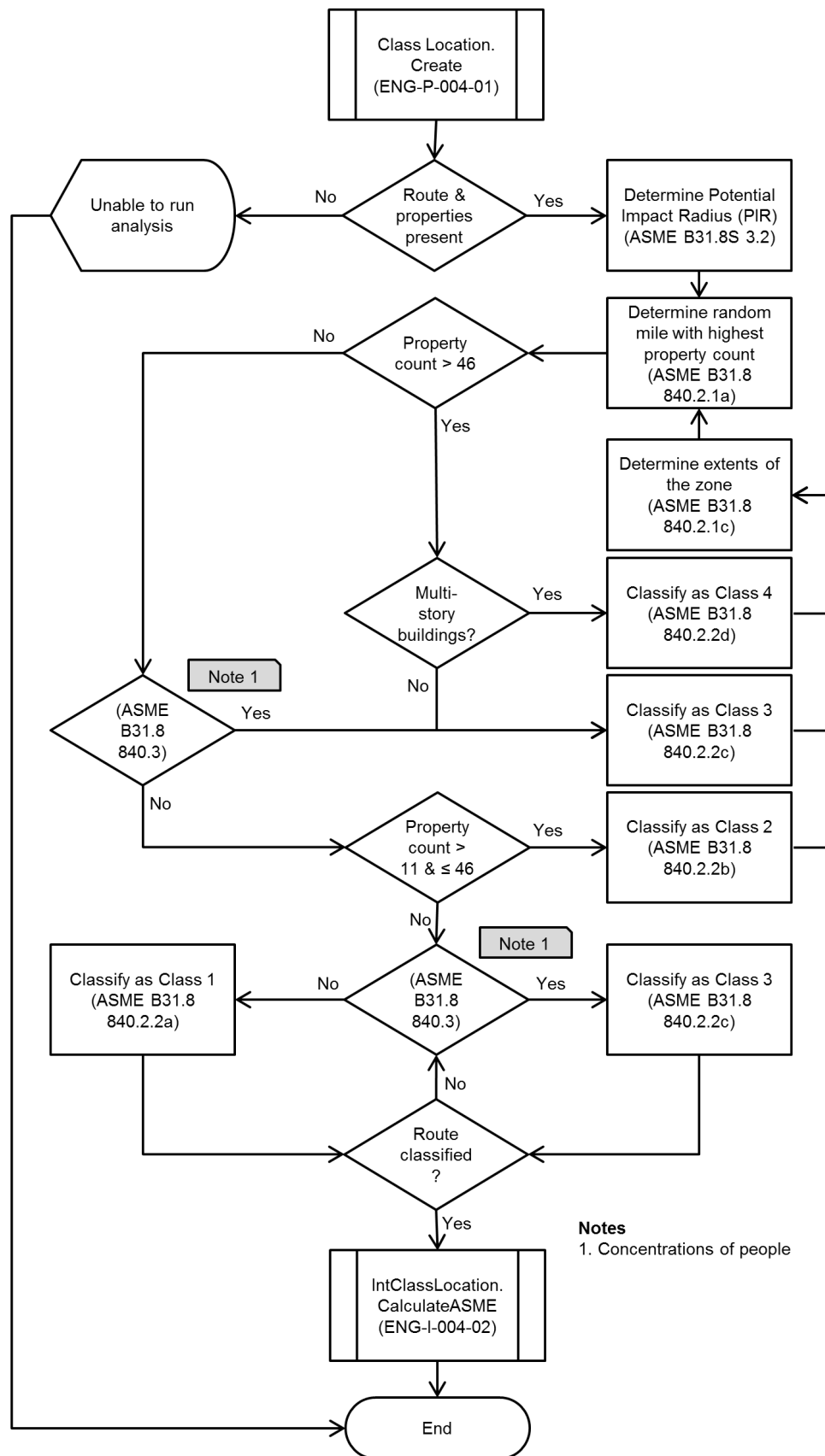


Figure 7.32 – ClassLocation.Create (ENG-P-004-01) Flowchart

Once this process is complete, the internal module (ENG-I-004-02) is called. This modifies the sections previously defined as location class 1 and 2, based on the **Crossing** and **Station** point feature classes (Table 7.2). An initial check is performed ensuring that the **DOTSegments** and the required feature classes for the analysis are present. Assemblies and cross connections in location class 1 areas are required to be location class 2 for a minimum of five times the pipe diameter or 3m, whichever is the lesser (ASME, 2012a: 39).

Facility	Location Class				
	1				
	Div 1	Div 2	2	3	4
Pipelines, mains, and service lines [841.2.1(b)]	0.80	0.72	0.60	0.50	0.40
Crossings of roads, railroads without casing:					
(a) Private roads	0.80	0.72	0.60	0.50	0.40
(b) Unimproved public roads	0.60	0.60	0.60	0.50	0.40
(c) Roads with hard surface and railroads	0.60	0.60	0.50	0.50	0.40
Crossings of roads, railroads with casing:					
(a) Private roads	0.80	0.72	0.60	0.50	0.40
(b) Unimproved public roads	0.72	0.72	0.60	0.50	0.40
(c) Roads with hard surface and railroads	0.72	0.72	0.60	0.50	0.40
Parallel encroachment on roads and railroads:					
(a) Private roads	0.80	0.72	0.60	0.50	0.40
(b) Unimproved public roads	0.80	0.72	0.60	0.50	0.40
(c) Roads with hard surface and railroads	0.60	0.60	0.60	0.50	0.40
Fabricated assemblies [841.1.9(a)]	0.60	0.60	0.60	0.50	0.40
Pipelines on bridges [841.1.9(b)]	0.60	0.60	0.60	0.50	0.40
Control and metering facilities [841.1.9(c)]	0.60	0.60	0.60	0.50	0.40
Compressor station piping	0.50	0.50	0.50	0.50	0.40
Concentration of people Classes 1 and 2 [840.3(b)]	0.50	0.50	0.50	0.50	0.40

Table 7.2 – Design Factors for Steel Pipeline Construction (Table 841.1.6-2)

(ASME, 2012a: 40)

Where the pipeline is parallel to, and encroaches on public roads and railways in location class 1 this is revised to location class 2.

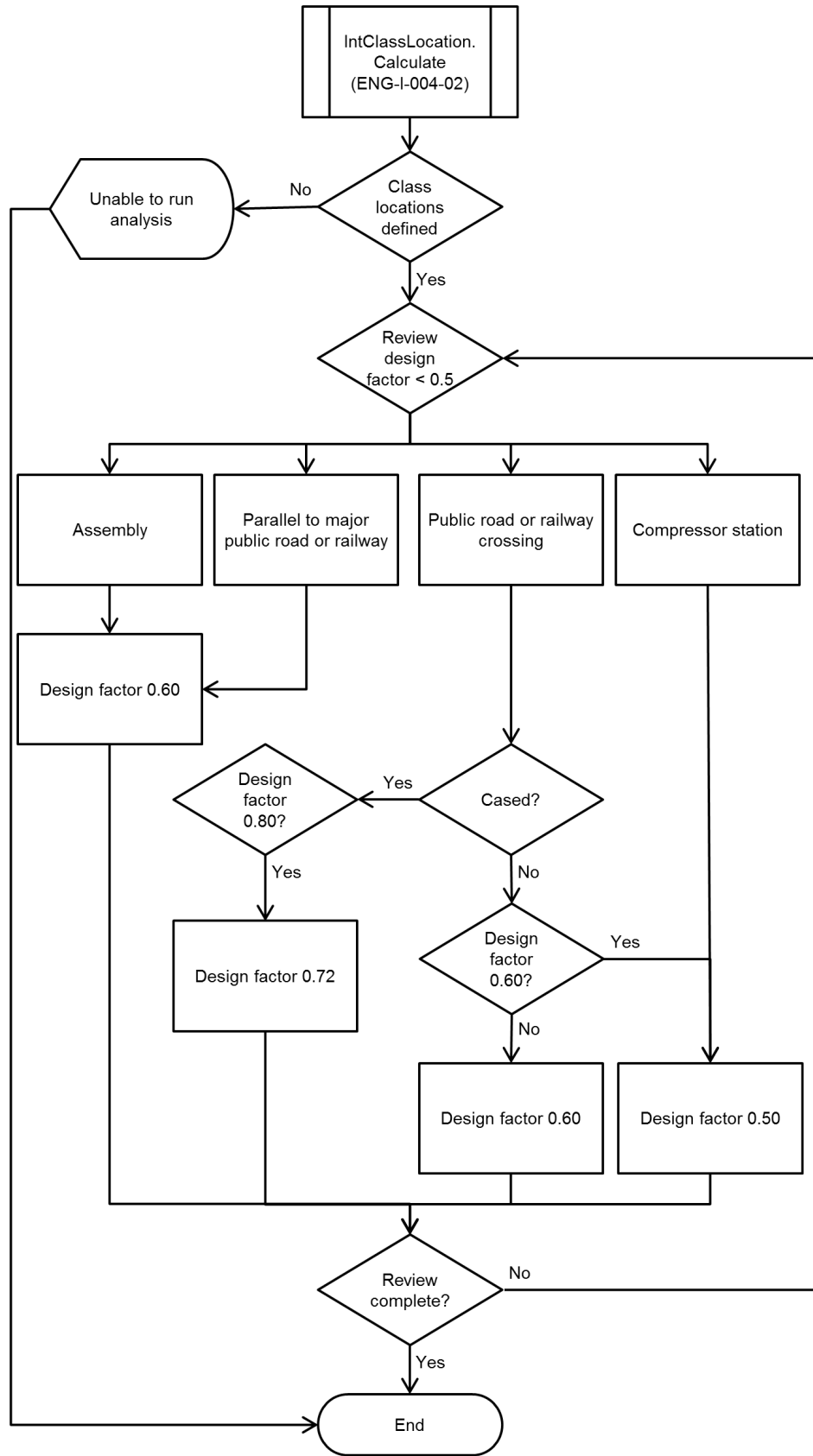


Figure 7.33 – IntClassLocation.Calculate (ENG-I-004-02) Flowchart

Based on the location of the **Crossing** feature class, public road and railway crossings are identified. Where these are in location class 1 and the crossing is cased, the location class is modified to location class 1, division 2. If the crossing is not cased it is modified to location class 2. Finally, all DOTSegments within the fence line of the compressor station are modified to location class 3. The activity flow diagram for this second module is shown in Figure 7.33.

7.6.3 Environmental Engineering

In order to undertake the SERA for any potential route, it is necessary to estimate the potential annual soil loss using the USLE. The crop management factor and the erosion control practice factor are generally considered as dimensionless constants when considering the soil loss in newly reinstated pipeline corridors. The slope steepness and length factors can be determined with accuracy using a DEM, but they are vector components in the USLE for the estimation of the soil loss for pipeline corridors as they are dependent on the route alignment; therefore, they need to be recalculated each time that the route changes. The remaining two inputs into the USLE are the rainfall erosivity and soil erodibility factors, both of which are scalar. Given the inherent uncertainty in determining these two factors from remote sensed data, these factors need to be determined and reviewed by an environmental engineer familiar with the issues of soil erosion. However, as these factors are scalar, they are calculated as previously discussed for the wider study area by the environmental engineer for the subsequent calculation of the soil loss using the USLE. These two raster datasets are converted into the vector feature classes **RainfallContours** and **SoilContours**, and imported into the PIEE in order to provide the *R* and *K* factors for the USLE respectively.

The **SoilErosion.Create** method (Figure 7.34) enables the user to determine the potential soil erosion risk for the current pipeline route. It checks that the crop management and erosion control practice factors have been set for the project and that the **ReinstatementProfile**, **SlopeAngle**, **SoilContour** and **RainfallContour** feature classes are present. Based on the **SlopeAngle**, any significant changes in direction of the simplified ground profile are determined, which in turn defines the extents of each **SoilErosion** polygon feature class. The slope angle and length factors are calculated and combined with the intersection with the **RainfallContour** and **SoilContour** feature classes, and the values set for the crop management and erosion control practice factors. The potential annual soil loss is then calculated using the USLE and the soil loss classification derived. The

components and the result of the calculation are stored as attributes of the **SoilErosion** feature class. By storing the constituent parts of the USLE as well as the estimated soil loss and classification (Table 5.1), it is possible to output this information as an aid for field verification.

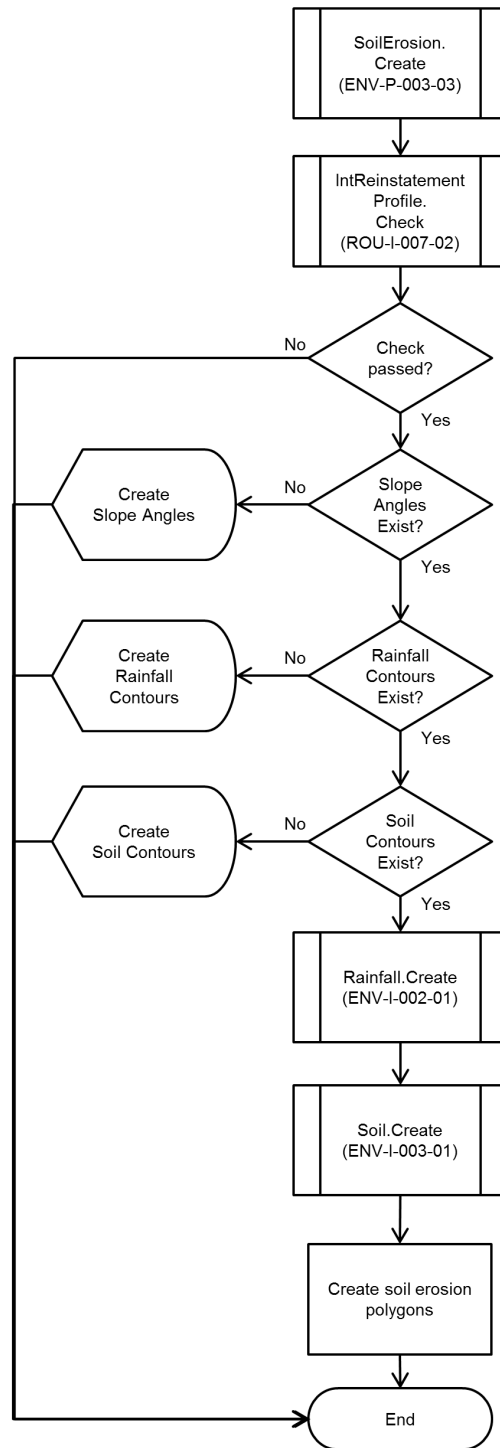


Figure 7.34 – SoilErosion.Create (ENV-P-003-03) Flowchart

Once the soil erosion risk has been determined, the **ReinstatementCode.Create** method (Figure 7.35) can be run to create the reinstatement codes for the pipeline. In having a second dataset based on the estimated soil erosion risk, the user is able to aggregate these codes if required using the **Add**, **Delete** and **Merge** methods of the **ReinstatementCode** feature class.

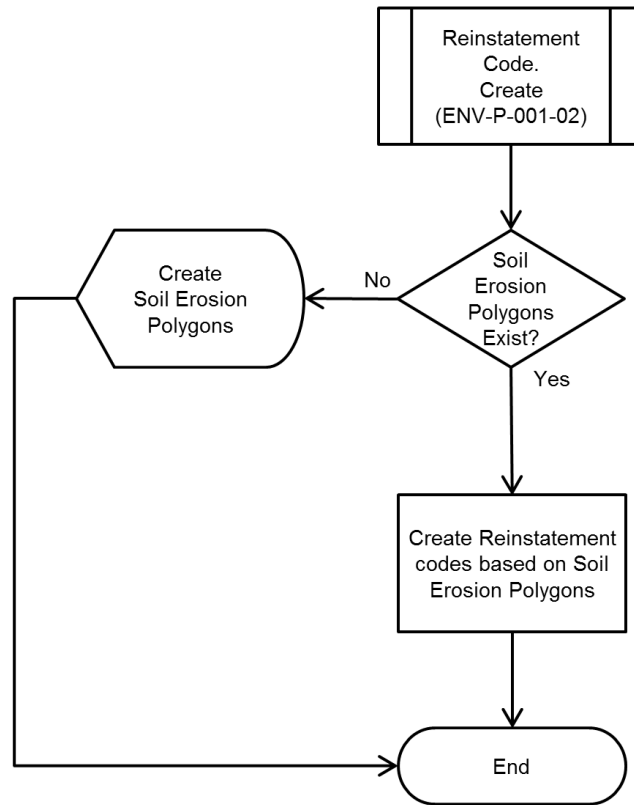


Figure 7.35 – ReinstatementCode.Create (ENV-P-001-02) Flowchart

7.6.4 Engineering Design

The main challenges facing the engineering designer during the pipeline design are the creation and revision of a large number of geospatial linear-referenced drawings and the problem of CGI. PIEE is able to create a number of different types of drawings. The drawings are in Appendix A1 to A10 of the SDS (Appendix E). In addition to the creation of drawings, all the data within the PIEE is available for export in tabular format, either in the form of a feature class report (DAT-P-002-02) or through the creation of user-defined schedules, which enable reports from multiple feature classes. These reports and schedules

form the basis for a number of key pipeline documents, including the pipeline material take-off (MTO), CP schedule, crossing schedule and the route definition report.

Drawings are grouped into drawing sets in order to handle the linear referencing. The user creates the drawing set and specifies the requirements for it. This includes the template to use, the numbering sequence, scales, and the data to be displayed. The data defining the drawing set is either stored within the model in AutoCAD dictionaries or attached to the template through the **Template.Create** module (Figure 7.36), which creates geometry defining the location and data to be displayed on the drawing. The user creates a template using the standard AutoCAD functions, which defines all the static elements such as, borders, logos and legends prior to running the **Template.Create** module. This module enables the user to define all the components of the drawing that will be incorporated and the settings for them. The method (DES-P-002-02) of defining these drawing set features is shown in Figure 7.36.

There are four types of component:

- **Text:** Existing text on the template may be used as placeholders for textual data held within the model. This includes drawing numbers, titles and model revision number.
- **Data bands:** These are areas defined by the user and set to display feature class attributes. The attribute value is inserted based on the 2D chainage of the attribute, so only **PIEE.Point** and **PIEE.Polygon** feature classes may be selected. The user determines how the data will be displayed.
- **Viewports and profiles:** The user may define areas of the template that will either display plan or profile views. For viewports, the user defines the scale, the area of interest (static or dynamic), grid requirements and orientation. The areas defined for displaying profiles also store the information on how the profile is to be stored, including direction, scale (horizontal and vertical), and lines to be profiled (**RouteProfile**, **GroundProfile**, **ReinstatementProfile** or **HydraulicProfile**).
- **Tables:** These are user-defined areas for displaying tabular data based on a feature class. These are similar to data bands in that only **PIEE.Point** and **PIEE.Polygon**

feature classes may be selected. The selected attributes are inserted and sorted by 2D chainage value.

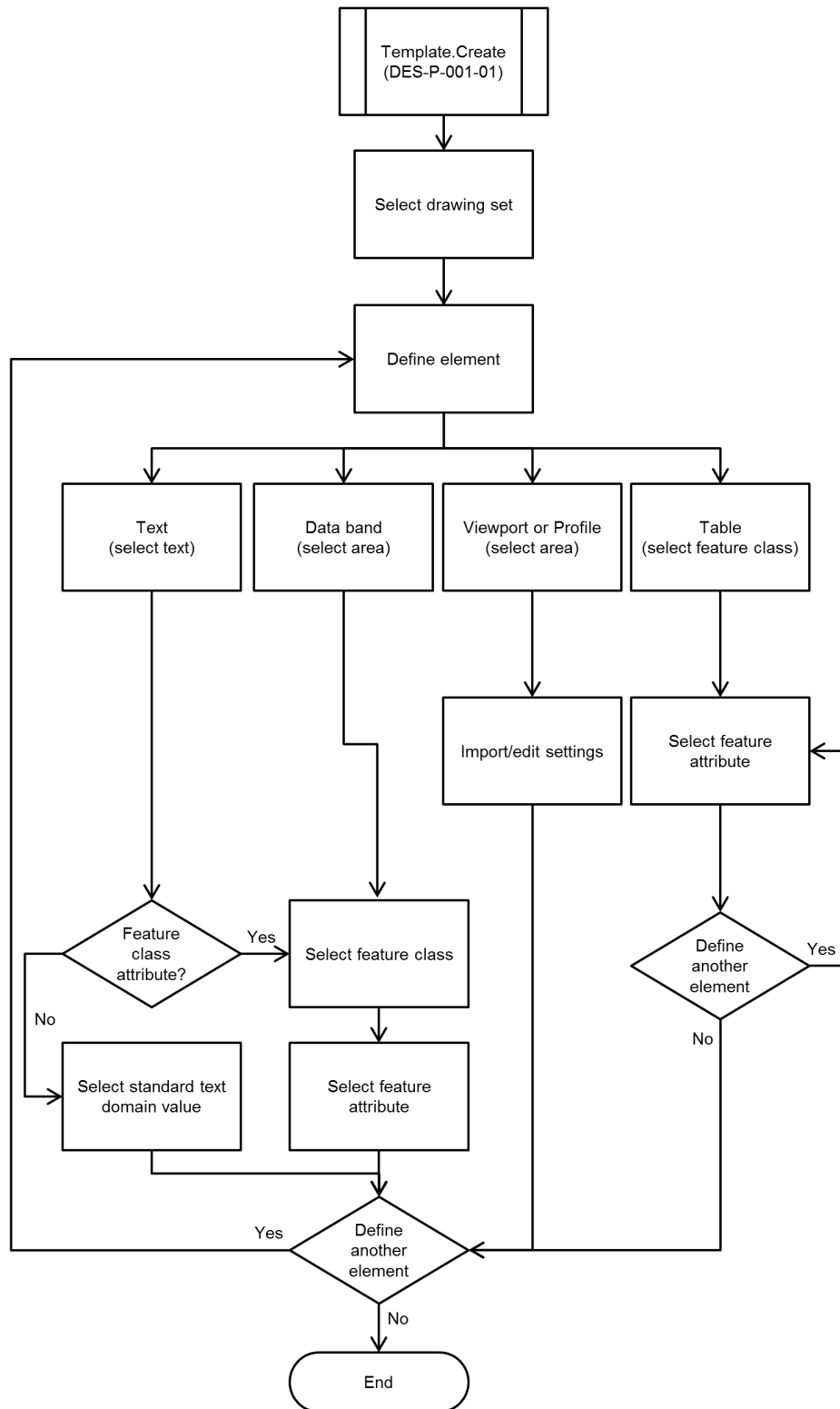


Figure 7.36 – Template.Create (DES-P-001-01) Flowchart

All of these drawings are produced using code with minimal requirement for editing by the design engineer. Where there are issues relating to presentation that the code is unable to resolve, such as the placement of labels where there are a large number of labels, this is edited by the engineering designer. Any changes made manually are stored within the model, so that these changes are recorded, and on subsequent generation or revision of the drawing, automated. While this approach offers significant savings in the time taken to produce the drawings, it also significantly reduces the time required to perform the checking.

As part of the development of the PIEE, a number of drawing sets have been created to demonstrate the drawing production functionality of the system. An example drawing from each of the drawing sets is included in the appendix of the SDS (Appendix E).

7.6.4.1 Drawing Sets

- **Route Maps:** These are plan drawings with a single viewport²⁸ (Appendix E: Appendix A1). They are used to provide a high-level overview of the pipeline route. They act as an aid to logistics, planning and site access. They are typically produced at a scale of 1:10000 and are generally orientated so that North is at the top of the drawing. They will normally show:
 - a mapping grid to aid the recording of information during site visits
 - KP markers showing the 2D chainage along the pipeline
 - location of major road, railway and river crossings
 - location of valve stations
 - key navigation features in proximity to the pipeline route
- **Strip Maps:** These are also plan drawings, but with two viewports. These drawings offer a similar level of information as the route maps at a larger scale, usually at 1:5000. To accommodate the two viewports, it is necessary to orientate the model within the viewport so that the pipeline is generally horizontal to the viewport. These drawings provide the initial route overview prior to the production of the alignment sheets. They are used by the pipeline engineer to refine the desktop route during the route walk. Once they are revised following the route

²⁸

An AutoCAD entity created in paperspace to provide a view of the modelspace in the drawing. The use of viewports enables multiple views of the model that are scale, orientation and display independent.

walk, they form the instruction for the surveyors to undertake the detailed pipeline route survey. These drawings can be produced in two different formats:

- **Type A:** The area covered in each viewport is different, enabling a consolidated set of drawings to cover the entire pipeline route, with the minimum number of drawings (Appendix E: Appendix A2).
 - **Type B:** The area covered in each viewport is the same, with the viewports containing different background imagery for the same extents. This enables the engineer to see both a topographical background at the same time as satellite or aerial imagery (Appendix E: Appendix A3).
- **Engineering Alignment Sheet:** These drawings are the primary document for the pipeline. They are the most detailed drawings; they show the entire pipeline route and are typically at a scale of 1:2500, showing 1 km for each drawing. All larger scale drawings only show discrete areas for major crossings, approaches to valve stations and areas of specific interest. They are used as the basis for the land acquisition and determination of compensation due to landowners and occupiers. They also provide the definitive information for the tertiary design and construction of the pipeline for the installation contractor (Appendix E: Appendix A4).

They provide a plan view that is orientated so that the pipeline is approximately horizontal on the drawing, with a coordinated grid and an indication of the limits of the drawing using match-lines. The plan uses a combination of satellite or aerial imagery to provide context and topographical data from the detail survey, including major features and elevation data represented as contours. Also indicated on the plan are the following:

- the locations of all the major crossings
- the intersection points that define the setting out of the pipeline route
- the RoW that defines the working area in which the installation contractor must perform the construction works
- any adjacent pipelines
- features within the RoW that will require protection during the construction of the pipeline (pylons, posts, etc.)

A ground profile, which is differentially scaled, is provided primarily to aid the installation contractors bending engineer to calculate the trench profile. Because of the scaling, it is necessary to split the profile to minimise the amount of space required to display it. Below the profile, details are provided for the engineering and environmental requirements. These include the following:

- for gas pipelines, the location class
- details of the pipe material including grade, diameter and wall thickness
- additional heavy wall requirements at crossings or other features
- increased cover requirements
- pipeline protection including concrete slabs, concrete coated pipe or set-on weights
- location of pipeline markers
- CP locations
- induction (factory formed) bend location with bend details
- reinstatement requirements, indicating the erosion classification
- RoW width, indicating areas of reduced working width and land boxes
- all pre-construction, construction and environmental constraints
- the limits of detailed drawings
- any areas that are subject to holds or specific notes

Supplementing this information are a number of tables. These typically include the coordinates for the geotechnical investigation locations, the coordinates and bend angles for the intersection points and the crossing details. This last table provides the description of each of the crossings including the depth or height of the feature, the width of the crossing and the angle of incidence of the crossing to the pipeline. Finally, standard information is provided on the template, such as a legend, standard notes and the design data sources.

Because of the efficiency of the production of these drawings, it is possible to provide different versions of the engineering alignment sheet tailored to specific engineering and environmental requirements.

- **Reinstatement Assessment Drawing:** This is a modified form of the engineering alignment sheet. The engineering and environmental data bands below the profile are replaced with the calculated inputs for the USLE, which were used to perform

the preliminary SERA from the remote sensed data and the estimated soil loss. Additional blank rows are provided for field observation. These drawings currently have no equivalent, and are produced to aid the SERA field investigation. (Appendix E: Appendix A5).

- **Environmental Alignment Sheet:** Similar to the reinstatement assessment drawing, it only displays information relating to the environmental constraints, while providing room for the capture of field notes. (Appendix E: Appendix A6).
- **Cadastral Alignment Sheet:** The engineering and environmental data bands below the profile are replaced with the owner and occupier book of reference (BoR) numbers and the linear easement and area in square metres for crop compensation. Details of the basis of the crop compensation and identification of land parcels are also included. (Appendix E: Appendix A7).
- **Preliminary As-built Alignment Sheet:** Traditionally the as-built alignment sheets have been produced by the installation contractor. As the requirement for drawings and data of greater sophistication and integrity grow, this is becoming an increasing challenge to the pipeline operator. The approach adopted in the PIEE is that the installation contractor is only required to provide as-built data in tabular form. By reducing the design overhead on the contractor, the time delay from installation and survey to transmission of as-built data is greatly reduced. With the increasingly complex systems being used, it is the engineer rather than the installation contractor who is better placed to undertake the production of the as-built documentation.

This drawing is similar to the engineering alignment sheet, but with the following differences. The drawing is produced with two pipeline routes. The first is the as-built centreline based on the weld location and data from the constructors' pipe data book; the second is the last approved for construction (AFC) route and all deviations recorded during the construction phase, identified with their respective change request numbers. This enables the field engineer supervising the construction to check that the as-built route is correct.

In addition to the reinstated ground profile, the top of pipe profile is also added, again as a differentially scaled profile. In place of the intersection points on the plan, profile and table of coordinates, these are replaced with the weld locations on the profile and table. Although all the weld locations are tabulated, only welds at approximately every 50m are shown on the profile. Finally, the data relating to the pipe including material, concrete coating and cover are added. This provides the initial as-built record. It should be noted that the chainage on this drawing is only approximate, to enable these drawings to be completed without the requirement of having continuous pipe data.

At this stage, the drawing is submitted to the site engineer for verification of the installed pipeline prior to the submission of any further as-built data from the contractor. (Appendix E: Appendix A8).

- **Final As-built Alignment Sheet:** This is a revision of the preliminary as-built alignment sheet. The AFC route and route deviation notices are removed and the final as-built information, including markers and CP is added. (Appendix E: Appendix A9). This approach ensures that the data within the PODS database matches the as-built drawings, as well as providing a means of validating the data within the database.
- **Standard Crossing Drawing:** There are three types of drawings detailing the requirements for crossings. There are typical drawings, which are non-site specific drawings detailing the typical requirements. These are not part of the system and are not automated, but are available from a library of typical details. The second type is for the major crossings requiring specialist-crossing methods. Drawings showing construction by HDD²⁹ and tunnel boring machines (TBM) cannot be created automatically and are subject to detail engineering by a pipeline engineer specialising in the design of these major crossings. The final and most prolific crossing drawing type is for the major standard crossings.

While the previous drawing sets are designed to provide continuous coverage for the pipeline route, the standard crossing drawing (Appendix E: Appendix A10) enables the user to create drawings of discrete areas of the route. The user is

²⁹

Horizontal Directional Drilling.

prompted to select the limits for the drawing and the scale is automatically selected, based on a user-configurable list of allowable scales.

The drawing has a plan orientated in the same way as for the alignment sheets. In addition to the standard functionality of a coordinate grid and labelled data, the user is able to create geometry and labels that are stored on a separate layer for the addition of entities that are not in the model, such as thrust and reception pits. The profile is drawn at the same vertical and horizontal scale, and has the ground and top of pipe profile. As for the plan area, the addition of manual input geometry is supported in the profile area. Below the profile area, data bands are created based on the drawing set template.

7.6.4.2 Building the PODS Database

The drawings are created through Visual LISP code, resulting in high quality documents, with considerable savings in draughting and checking time. Once produced these drawings are checked and issued; at these fixed maturity levels, the data is extracted from the database through Visual LISP code to tab-delimited files. These files directly replicate the PODS table and attribute structure, with all GUIDs and relationships being created at this stage. This part of the process takes under two minutes for a pipeline route of over 450km (Figure 7.37).

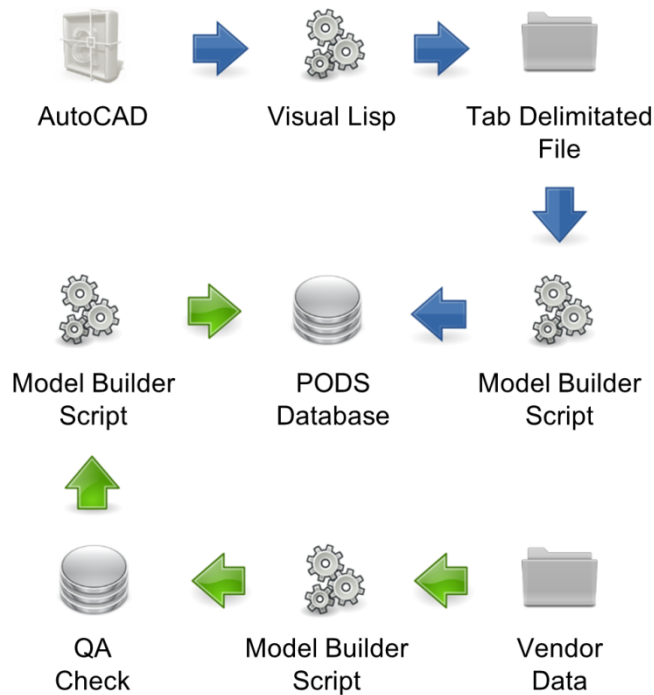


Figure 7.37 – Importing Design and Vendor Data

The tab-delimited files can be viewed and checked externally to verify and validate the Visual LISP code. These files are then used by an ESRI Model Builder script to populate the PODS model. The model then provides the data for the webGIS³⁰ to deliver the data to the project stakeholders; this entire process is achieved in a few hours.

This is shown in the second part of Figure 7.37. The vendor is issued with data templates in Excel; these templates identify all the PODS attributes required irrespective of the table that they reside in, thereby simplifying the process for the vendor. In addition, the spreadsheet contains a data dictionary for the required attributes. Finally, the templates contain some Visual Basic for Applications (VBA) macros that the vendor can run in order to check for missing data or incorrect data types prior to submission.

These spreadsheets are then processed using ESRI Model Builder scripts to verify the data integrity; if the data is good, GUIDs are created and the data outputted to a holding database for further QA/QC. Once final checking is complete, the data is imported into the PODS

³⁰ A webGIS is a GIS designed for delivery across the internet or intranet. It includes server software to enable multi-user transactions, such as the ESRI ArcSDE software and an application-programming interface to serve geospatial data from a database.

database using an ESRI Model Builder script. It should be noted that at this stage no geometry is created from the vendor data.

In a similar method used for the gathering of vendor data, the pipeline installation contractor is supplied a number of Excel spreadsheets as templates for collecting, submitting and verifying the as-built data prior to submission. The files are then checked using VBA code, and if accepted, GUIDs are added to those items where there is not a corresponding vendor GUID, such as CP test post or pipeline marker. These files are then converted to tab-delimited files with the PODS table and attribute structure, allowing validation of the VBA code. These files are then used by an ESRI Model Builder script to import the data into the model, adding the required relationships to the vendor data (Figure 7.38).

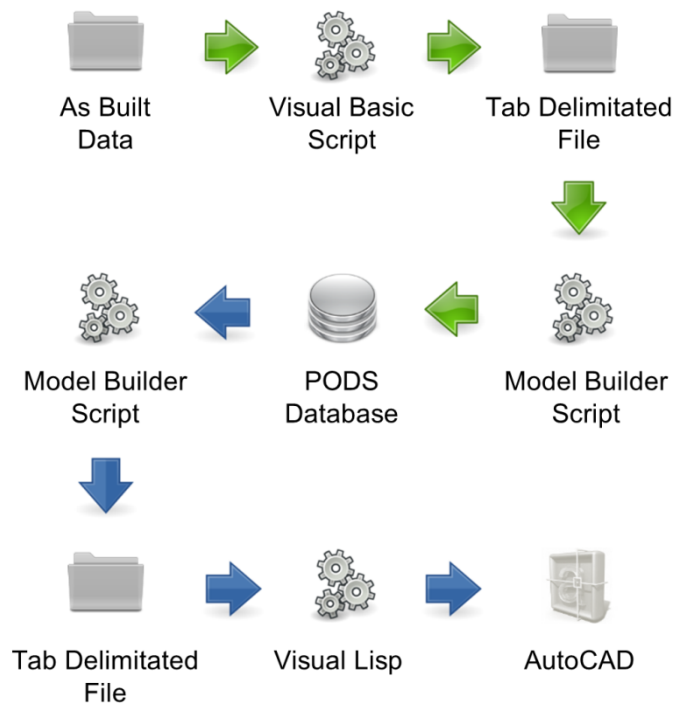


Figure 7.38 – As-Built PODS Model Validation

In order to validate the final model, the data is extracted using ESRI Model Builder scripts to generate the tab-delimited files. These files are then used by Visual LISP code to create a CAD model of the PODS model.

From the CAD model, using the same Visual LISP code used to generate the design alignment sheets, drawings are automatically created, which are then reviewed against the contractor-supplied red line mark ups.

A crucial component of the system is the ability to disseminate information across the project stakeholders accurately and quickly. The obvious platform for this is the internet, with the ArcGIS web services. This is facilitated by the creation of ArcGIS model builder scripts to import CAD model data into the PODS format, enabling the issued design to be disseminated across the wider project team immediately.

7.6.4.3 Schedules

In addition to automated drawing production, there is the capacity to generate schedules based on user-defined templates from data in the PIEE model. Although there is the ability to export any feature class data to a tab-delimited file using the **Feature.Export** method, schedules provide the user with the ability to create complex reports spanning feature classes with the use of a primary key to join the different feature classes. Schedules are defined using the **Schedule.Define** method (Figure 7.39). This also supports user-defined column headings. Once a schedule is defined, it can be run using the **Schedule.Create** method.

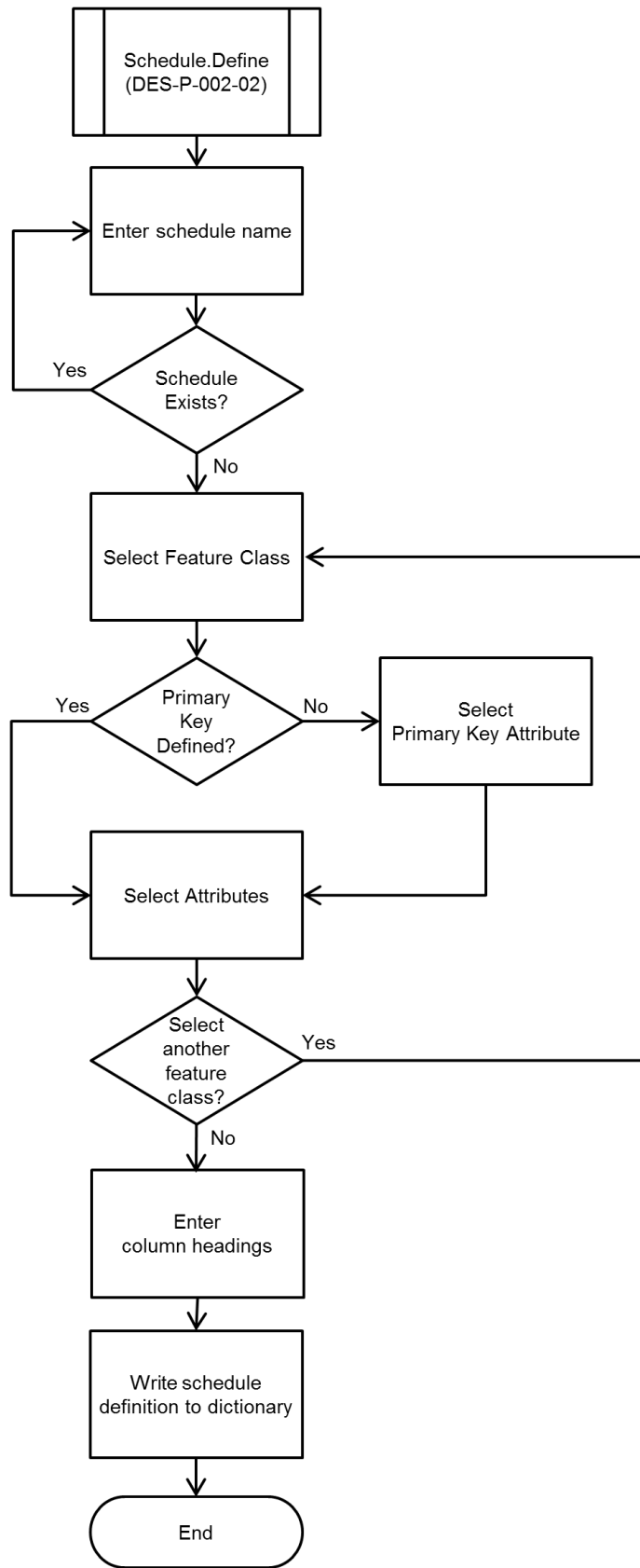


Figure 7.39 – Schedule.Define (DES-P-002-02) Flowchart

7.7 Discussion

The system presented is data-centric, potentially software independent, and based on an industry standard schema; it is also function rather than discipline specific. This approach improves data interoperability and reduces the number of discipline interfaces. By exposing the core geospatial components in both the GIS and CAD platforms, users are able to access and analyse the data using the software tools of their choice, further reducing perceived interoperability issues. Whereas a structured database schema is important, the use of an industry standard schema with compliant modifications allows the data to be shared across organisations as required by the pipeline operator. Given that pipeline operators frequently use different engineering consultants for the various phases of the pipeline project, this provides significant cost and schedule savings in transferring geospatial engineering data between companies at different stages in the project development.

Although the aim has been to reduce the number of interfaces, the use of clearly defined programming interfaces between CAD and GIS recognises that the required skill sets are likely to be distributed across the design team. However, in line with the requirements of interoperability, these programming interfaces are transparent to the final user.

This approach demonstrates the value of an integrated system for the solving of geospatial engineering problems, such as the determination of location class or for performing high-level screening hydraulic analysis of the proposed pipeline route. It also enables the pipeline engineer to help to improve the route definition from an environmental perspective. Central to the system is the concept that the model is the primary deliverable from the design activity as opposed to the drawings and associated schedules, which are automated outputs from the model. While the proposed solution does not resolve all the issues facing the pipeline engineer, it does address some of the key issues of CGI and presents an integrated approach focusing on functional requirements.

In their paper, Wright et al. acknowledge two key points in the design of GIS applications. Firstly, that the developers need to have a background in a range of disciplines including computer science, engineering, design, mathematics in addition to geography and GIS; and secondly, that academics in general are not best suited to the development of reliable commercially viable software (1997: 356). Clearly, there are exceptions to this last point, but in general, it is true. This is relevant to the current research in that it has required a broad range of skills and knowledge in order to undertake the development of the PIEE and that it

is not the aim to produce a robust commercially ready software application; rather it is to prove the value of the approach.

Chapter 8

RESULTS AND EVALUATION OF THE AEGIS

This chapter presents the results from the development of the PIEE and its evaluation using the DSRM approach (**Research Objective 4**).

In the discussion on methodology (Chapter 3), the value of the instantiation of the artefact as a means of assessment of the constructs, models and methods within the field of design science was established. Therefore, the instantiation of the artefact or system provides an appraisal of the premise on which it is founded. In order to evaluate the PIEE, the DSRM methods were reviewed and the rationale for the inclusion or exclusion of the method from the evaluation of the PIEE presented. Based on this polychotomous approach to the evaluation, the results are presented alongside the evaluation.

The PIEE has been used on the SCPX pipeline project. In doing so, it has been possible to generate real metrics about performance to enable an evaluation based on the demands of a real project. However, due to the timing of the development of certain components of the system, they have not been available to use on the SCPX project; where this is the case, comparisons have been made to past projects.

Artefact instantiation demonstrates feasibility both of the design process and of the designed product.

(Hevner et al., 2004: 84)

8.1 Methodology

The evaluation of the PIEE is based on the framework (March and Smith, 1995: 260) presented in Section 3.6, which provides five categories for the evaluation of the system.

8.1.1 Observational

The aim of the observational evaluation is to determine how the artefact performs in a real environment. This is a qualitative approach where the researcher/observer would not directly interact with the environment. Although in this instance the observer is interacting with the environment, this evaluation method has been selected because it provides a holistic evaluation of the system within a real-world environment. This type of evaluation can be of one of two types:

- **Case Study:** This approach requires the detailed contextual observation of the artefact for a specific project. The PIEE has been used on the SCPX project and this is used as a case study. This project aims to increase the existing SCP pipeline capacity through additional compression facilities and the installation of a significant length of looped pipeline. Because of this, the route selection for the new looped pipeline is limited; from an operational perspective, there is a requirement to minimise the deviation of the looped pipeline route from the existing SCP route. Where deviation is required, usually due to constructability issues, then the scope for route optimisation due to hydraulic requirements is limited. Because of this, the preliminary hydraulic analysis and location class functionality is not evaluated using this method.
- **Field Study:** The field study requires the use of the artefact across a range of projects. Usually not as detailed as a case study, it seeks to broaden the contextual environment. This is particularly useful for artefacts designed to operate across a number of environments. This evaluation method requires the use of the PIEE across a range of projects. This has not been possible and therefore this method of evaluation has not been used.

8.1.2 Analytical

Analytical evaluation involves the analysis of the internal, architectural and performance characteristics of the artefact:

- **Static Analysis:** This looks at the complexity of the artefact and enables an evaluation of the structure of the system. This is applicable to evaluating the structure and coding of the PIEE.
- **Architecture Analysis:** This seeks to provide an evaluation of the artefact from an interoperability perspective. This, together with the static analysis, will form the basis of the evaluation of the coding of the system.
- **Optimisation:** This either identifies the properties of the artefact that have been optimised or the boundaries for optimal performance of the artefact. This will be used to evaluate the pipeline hydraulics and location class determination, because these two components are potentially computationally intensive.
- **Dynamic Analysis:** This evaluation looks at the performance of the artefact. A key aim of the PIEE is performance. Therefore, this method will be used for the evaluation of all components.

8.1.3 Experimental

This form of evaluation can be used to evaluate components of the system to existing systems:

- **Controlled Experiment:** An evaluation method involving control of the individual variables (input data) enabling the determination of the impact of the variables to the result observed. This is not applicable to the PIEE. However, similar to this approach at a function level is black-box testing, which is being conducted.
- **Simulation:** The evaluation of a model of a real-world environment, validated to observations or other models. This approach has been adopted for the hydraulic modelling, location class determination and the soil erosion risk components. For the hydraulic modelling, it enables verification of the numerical results against industry standard proprietary software. For the remaining two components, it has validated the results given a number of different input values.

8.1.4 Testing

Software testing enables the verification and validation of the software. Verification determines if the software performs as it should, that is that the logic outlined in the activity flow diagrams has been correctly coded. This activity typically is an integral part of the design phase. Validation, however, seeks to ensure that the software meets the aims and requirements specified in the SDS; that it delivers the solution required. This process is normally performed towards the completion of the design phase (Williams, 2013: 36).

Testing falls into two broad categories: functional (black-box) and structural (white-box). Where testing is based on both functional and structural methods, it is referred to as grey-box testing. The main difference between the two methods of software testing is in the opacity of the test to the tester (IEEE, 2010). Both forms of testing have been employed during the development of the PIEE for all the components (Patton, 2006: 55):

- **Functional:** Black-box evaluation focuses on the outputs from the system based on known inputs and conditions, and is frequently carried out by others rather than the programmer. In this case, the structure of the system is not exposed to the tester.
- **Structural:** White-box evaluation, however, requires both a detailed knowledge of and access to the internal structure (code) of the software, and is typically performed by the programmer.

8.1.5 Descriptive

The final method for evaluation involves the demonstration of the utility of the developed artefact. This can be based on a comparative analysis of existing systems or the demonstration of the value of the artefact in different scenarios (Dresch et al., 2014: 99):

- **Informed Argument:** This is typically a comparative evaluation of the artefact against comparable existing systems. A comparative review of a number of the current proprietary systems being used has been performed. This gives a contextual evaluation of the system, though the evaluation is restricted to information about the systems in the public domain.
- **Scenarios:** This evaluation method aims to demonstrate the applicability of the artefact to a range of different scenarios or environments. Although the application

of the approach adopted in the PIEE could apply to the design of offshore pipelines, which is raised in Chapter 9, it has not been explored further at this stage.

8.2 Results and Evaluation

The methods selected for the evaluation of the components of the PIEE are tabulated in Table 8.1.

Component	Evaluation Method								
	Case Study	Static Analysis	Architecture Analysis	Optimisation	Dynamic Analysis	Simulation	Black-box Testing	White-box Testing	Informed Argument
Structure of classes and code		✓	✓						
Pipeline hydraulics				✓	✓	✓	✓	✓	
Location class determination				✓	✓	✓	✓	✓	
Soil erosion risk assessment	✓				✓	✓	✓	✓	
Production of drawings sets	✓				✓		✓	✓	
Generation of schedules	✓				✓		✓	✓	
System functionality and performance overview					✓				✓

Table 8.1 – System Component Evaluation Matrix

The following sections present the evaluation for the PIEE by component, as identified in Table 8.1.

8.2.1 Static and Architecture Analysis

PIEE components:

- structure of classes and code

As part of the code compliance, the code has been written to a common standard. An example of the code created for the PIEE is attached in Appendix F. The code (Visual LISP) has been written using Crimson Editor (version 3.70); an ASCII text editor that supports

customised colour syntax coding. The code has been grouped into files by function. Each file has a header and end of file marker, with every function having its own header and divider. As can be seen in Figure 8.1³¹, comments are prefixed with a semicolon (shown in green). Functions that have been written as part of this research and that are in the PIEE or acLib library are shown in red, with the standard (internal) Visual LISP functions in blue.

³¹ *This function has been shortened in order to reduce it to a single page. The full function is presented in Appendix F.*

```

;*****
; Module:      PIEE_PODS-Export
; Status:      Issued
; Revision:    01.001
; Description:  PIEE PODS Export Function Library
; Written By:  Keith Winning
;
; -----
; Function Listing
; -----
;
; p_PODS-Export           Exports the PIEE model data to PODS tables
; p_PODS-ExportCheckVariables  Checks that the fixed variables required for the
;                               table are present
; p_PODS-AddValue         Builds the table entry for an individual record
; p_PODS-ExportLineLoop   Builds the PODS LineLoop table
; p_PODS-ExportStationSeries  Builds the PODS StationSeries table
; p_PODS-ExportControlPoint  Builds the PODS ControlPoint table
;
; =====
; Declare Functions
; -----
;
; Function:    p_PODS-Export
; Purpose:     Exports the PIEE model data to PODS tables
; Syntax:      (p_PODS-Export)
; Inputs:      None
; Returns:     None
; References:  acLib, dosLib
; Notes:      1. The Table/Field mapping is defined in the PODS Table Mapping.ini
;              file which should reside in the PODS sub folder of the project.
;              2. The order that the tables are created is critical as data is defined
;                 during table creation which subsequent tables depend on.
; -----
(defun p_PODS-Export ( / t1 path ifile elst handle 2d2 date cdata tk rk t2 tt)
  (Err_FunctionList "p_PODS-Export")
  (setq path (strcat (getvar "dwgprefix") "PODS\\"))
  (setq ifile (strcat path "PODS Table Mapping.ini"))
  (if (= (findfile ifile) NIL)
    (alert "Error Unable to find 'PODS Table Mapping.ini' file")
    (progn
      (setq t1 (Dtm_SystemTime "HH:MM:SS"))
      (setq elst (IPD_Rou-GetRoute "3D"))
      (setq handle (cdr (assoc 5 (entget (car elst)))))
      (setq 2d2 (rtos (cdr (assoc "2D Length" (ply_info elst))) 2 3))
      (setq date (Dtm_SystemDate "DD/MM/YYYY"))
      (setq cdata (list (cons "$Route3DHandle" handle)))
      -> Lines removed
      (setq cdata (p_PODS-ExportStationSeries cdata))
      -> Lines removed
      (setq tk (itoa (cdr (assoc "TableCount" cdata))))
      -> Lines removed
      (setq t2 (Lst_String->List t2 ":"))
      (setq t1
        (+ (* (atoi (nth 0 t1)) 360) (* (atoi (nth 1 t1)) 60) (atoi (nth 2 t1)))
        ) ;setq
      (setq t2
        (+ (* (atoi (nth 0 t2)) 360) (* (atoi (nth 1 t2)) 60) (atoi (nth 2 t2)))
        ) ;setq
      (setq tt (itoa (- t2 t1)))
      ) ;progn
    ) ;if
  (Err_FunctionList NIL)
  (princ
    (strcat
      "\n\t" tk " PODS tables with " rk " attributes created in " tt " seconds."
    ) ;strcat
  ) ;princ
  (princ)
) ;defun
; -----

```

Figure 8.1 – Extract of the p_PODS-Export Module

The system has been developed in Visual LISP, a derivative of the lisp programming language. With the OOP approach of abstract and feature classes following the rules of inheritance, the system could be ported from AutoCAD/ArcGIS to another CAD/GIS platform if required. The SDS provides the structural documentation in order to support this cross platform approach.

8.2.2 Black-box and White-box Testing

PIEE components:

- pipeline hydraulics
- location class determination
- soil erosion risk assessment
- production of drawing sets
- generation of schedules

During the course of the development of the PIEE, the following types of white-box testing were conducted by the programmer for all functions:

- **Unit Testing:** This is carried out prior to the integration of the code into the system. This form of testing is essential; the faults within the code are easier to locate and this method can account for identifying the majority of the faults within the code. In order to support this early on in the development, use was made of stub³² programs and scaffolding code³³. These programs were used to replace dependent code modules that had not been created or to provide checks as to the values being passed to subordinate functions.
- **Integration Testing:** Prior to integrating code into the system, all functions were tested for integration to other dependent functions. In addition, this was done for all functions called from the user interface.
- **Regression Testing:** Where functions were revised, this was carried out to ensure that there were no faults being introduced into the system.

At certain stages of the system maturity, the following black-box testing was undertaken:

³² *Computer program statement substituting for the body of a software module that is or will be defined elsewhere.*

³³ *Computer programs and data files built to support software development and testing but not intended to be included in the final product.*

- **Functional and System Testing:** This ensured the programmer and the potential users of the system to test the system against the functional requirements stated in the SDS. It also enabled stress testing of the system.
- **Acceptance Testing:** This ensures that the system is able to deliver to the quality/performance parameters in the SDS. Although the system is not subject to a formal acceptance test and handover, these tests were used to determine the performance of the system.

8.2.3 Optimisation

PIEE components:

- pipeline hydraulics
- location class determination

The hydraulic analysis has been optimised by using Equation 4.6 to determine the friction factor and by simplifying the hydraulic model. The location class determination was optimised through the application of the programme flow logic in accordance with the activity flow diagram. This ensured that once the current segment was location class 1, all remaining segments were classified as location class 1.

8.2.4 Dynamic Analysis

PIEE components:

- pipeline hydraulics
- location class determination
- soil erosion risk assessment
- production of drawing sets
- generation of schedules
- system functionality and performance overview

This testing was primarily carried out to determine the performance of selected components during run-time. The only component that required significant time to create was the drawing sets. This is discussed in Section 8.2.6 (Case Study).

8.2.5 Simulation

PIEE components:

- pipeline hydraulics
- location class determination
- soil erosion risk assessment

This evaluation method is suited to systems using simplified computer models to model real world phenomena such as computational fluid dynamics and FEA. The hydraulic modelling component has been evaluated by comparing the output from the same model in both the PIEE and PipeFlo, a proprietary pipeline hydraulic analysis application for Newtonian fluids. The results are summarised in Table 8.2.

Case	Flow Rate (mbd)	NPS (Inches)	Total Pump Power Requirements				Pump Stations Required		
			PipeFlo (MW)	PIEE (MW)	Difference (MW)	Difference (%)	PipeFlo	PIEE	Difference
1	300	22	74.52	75.1	0.58	0.78	13	14	1
2	300	24	45.84	48.64	2.8	6.11	8	9	1
3	300	26	34.4	32.36	-2.04	-5.93	6	6	0
4	300	28	22.91	21.52	-1.39	-6.07	4	4	0
5	200	18	64.91	64.44	-0.047	-0.72	17	18	1
6	200	20	38.17	39.35	1.18	3.09	10	11	1
7	200	22	22.88	21.45	-1.43	-6.25	6	6	0
8	200	24	15.28	14.51	-0.77	-5.04	4	4	0
9	100	16	15.28	16.07	0.79	5.17	8	9	1
10	100	18	9.53	9.06	-0.47	-4.93	5	5	0
11	100	20	5.72	5.43	-0.29	-5.07	3	3	0
12	300	24	45.9	42.95	-2.95	-6.43	8	8	0
13	300	26	34.25	32.22	-2.03	-5.93	6	6	0
14	300	28	22.81	21.6	-1.21	-5.3	4	4	0

Table 8.2 – Summary of Hydraulic Evaluation

Comparing the results obtained for the total pump station power requirements in terms of the percentage, the range is $\pm 6\%$ between the two systems. For the isothermal cases where a larger number of pump stations was required (cases 1, 2, 5, 6 and 9), the PIEE has generally required one additional pump station. Although not ideal, it at least is on the conservative side of the results obtained by PipeFlo. This demonstrates that the PIEE is capable of performing preliminary high-level hydraulic analysis within acceptable limits, though further refinement should lead to results that are more accurate.

The location class determination was tested out using simplified building location data to determine that the modelling was correct. The SERA modelling was validated as discussed in Chapter 5.

8.2.6 Case Study

PIEE components:

- soil erosion risk assessment
- production of drawing sets
- generation of schedules

The PIEE has been developed during the course of the SCPX pipeline project. As previously discussed, due to project requirements it has not been possible to evaluate properly all components of the PIEE for this project. However, those assessed have performed well. The approach to the SERA has enabled a reduced schedule and cost implication for the subsequent field investigations, and the development of the reinstatement assessment drawings has provided a method for validating and capturing changes to the model inputs. The schedules, which are generated automatically from the system, have provided a significant improvement in the production of the associated documents such as the crossing and CP schedules and linepipe MTO. Table 8.3 lists the drawing sets that the PIEE can produce and shows those that have been used on this project. These drawings are in Appendix A1 to A10 of the SDS (Appendix E).

Drawing Sets	Number of drawings by country	
	Azerbaijan	Georgia
Route map ³⁴	0	0
Strip map (Type A) ³⁴	0	0
Strip map (Type B)	70	11
Alignment sheets (Engineering)	424	63
Alignment sheets (Reinstatement)	424	63
Alignment sheets (Environmental) ³⁴	0	0
Alignment sheets (Cadastral) ³⁴	0	0
Alignment sheets (Preliminary as-built) ³⁵	424	63
Alignment sheets (Final as-built) ³⁵	424	63
Standard crossing drawings ³⁴	0	0
Total drawings by country	1766	263
Total drawings	2029	

Table 8.3 – SCPX Drawing Sets

Although not all the drawing sets were used, largely as the drawings had already been produced prior to the PIII functionality becoming available, a significant number of drawing were created through the system. For each country, there was a separate model and due to the length of the pipeline within each country, the model file size varies and consequently the drawing generation time. Table 8.4 shows the performance metrics for the creation of the engineering alignment sheets for both Azerbaijan and Georgia. With only two computers, it is possible to create and print all the engineering alignment sheets for Azerbaijan overnight, while for Georgia the sixty-three alignment sheets can be created in a little over one hour. The saving both in terms of draughting and checking time is considerable when the number of revisions that are required is considered.

	Azerbaijan	Georgia
Model size (Mb)	80	22
Number of alignment sheets	424	63
Minimum time to create alignment sheet (sec)	115	60
Maximum time to create alignment sheet (sec)	165	110
Time to create drawing set (sec)	49820	4095
Time to create drawing set (hours:minutes)	13:50	01:08

Table 8.4 – Drawing Set Performance (Alignment Sheets)

³⁴ *These drawings were not created using the PIII.*

³⁵ *These drawings have not been created yet, but are due to be produced in the next two years.*

8.2.7 Informed Argument

PIEE components:

- System functionality and performance overview

The method has been conducted by providing a brief narrative of the seven existing proprietary systems with a comparison to the PIEE. The key differences are summarised in a table at the end of the section. This gives a contextual evaluation of the system, though the evaluation is restricted to information about the existing systems in the public domain.

8.2.7.1 *ESRI Route Optimisation Interface (EROI)*

This software comprises a python script, an ArcGIS toolbox, sample data and documentation (ESRI Utility Team, 2011). It has been developed as a tutorial with the potential to be expanded into a project-specific solution. The stated purpose is to allow an engineer to evaluate all the cost factors in a single calculation resulting in a least-cost path (polyline). The least-cost path is calculated using the individual cost factor layers to create a single cost grid, where the cell has a summation of the individual cost factors with a user-defined weighting to define the relative importance of each cost factor.

Pipeline hydraulic analysis is not included in this model. The approach used in this model precludes hydraulic modelling, as it cannot produce a grid with fixed cell cost. This is because the hydraulic cost and feasibility is dependent on the fluid properties, pipeline size, elevation and the cumulative effects and therefore route of the pipeline.

8.2.7.2 *Secon Alignment Sheet Generator (SASG)*

The key features of this system (Secon, 2014) are the following:

- a single total station file in CSV format that generates the basic Alignment sheet
- additional data like population density, soil resistivity/soil investigation, and land details that are entered into a database
- automatic generation of drawings

While it offers similar functionality with respect to drawing production, it offers no engineering or environmental calculations. The population density is a pre-determined input to the model rather than a dynamically calculated input based on the route of the pipeline.

8.2.7.3 *Blue Sky Developments Lightning (BSDL)*

Blue Sky Developments produce two software packages for the creation of pipeline alignment sheets. The first, Lightning, is based on the ESRI ArcMap platform.

The key features of Lightning (BSD, 2014a) are as follows:

- the generation of induction bends
- dynamic warnings and recommendations that help to prevent mistakes
- template wizard extension (separate application)
- automatic generation of drawings with optimised widths, angle and alignment to the centreline
- creation and display of multiple profile surfaces
- PODS support

All of these features are present in the PIEE, and there is no mention of engineering or environmental calculations. Like most of the other systems, it concentrates solely on the automated production of alignment sheets; it does not appear to support generation of other drawing types.

8.2.7.4 *Blue Sky Developments Skyline (BSDS)*

The second application from Blue Sky Developments, Skyline, is based on the AutoCAD platform. It has similar key features to Lightning and the following additional features (BSD, 2014b):

- it writes to a Microsoft Access database
- the enterprise version of Skyline writes to SQL Server
- it inserts points from a csv directly into your dwg
- it provides dynamic previews that help you get settings right the first time
- it generates sheets left to right, and right to left
- it is compatible with metric and Imperial units
- data is loadable into PODS

Again, all of these features are available in the PIEE, and as with Lightning, no engineering functionality is provided.

8.2.7.5 *Eagle Mapping Turbo Route (EMTR)*

Eagle Map Turbo route is an application for the generation of alignment sheets based on the ESRI ArcGIS platform. It is compatible with all the pipeline data models, PODS, APDM and ISAT. In addition it offers the following key functionality (EIM, 2014):

- multiple band styles
- embed dynamically created tables, inset maps and scale bars
- advanced labelling options
- multi-line support
- multiple plan views
- hyperlinking
- connection to data sources within ArcMap and ODBC
- user and batch sheet generation and plotting

With the exception of the multiple plan views, all the other key functions are available in the PIEE. This functionality is provided in the PIEE but only for strip maps; these are drawings with two plan views and no profile.

8.2.7.6 *New Century Software HCA Analyst (NCSHCA)*

The HCA Analyst software from New Century Software performs the location class determination for gas pipelines based on the American DOT regulations (ASME B31.8). Key features of this software include the following (NCS, 2014a):

- identification of high consequence areas
- addition of metadata, showing how the area has been classified
- results available in both geospatial and tabular formats
- automated approach to reduce errors
- the enabling of what-if scenarios to be performed

This offers very similar functionality to that of the PIEE, and like the PIEE, is currently limited to the American DOT codes. However, the PIEE currently performs this in an AutoCAD environment, which is arguably more familiar to a greater number of engineers. The major difference between the systems is that this software does not offer any other functionality of the PIEE.

8.2.7.7 *New Century Software SheetCutter (NCSS)*

This alignment sheet software from New Century Software is based on the ESRI ArcGIS platform and offers the following (NCS, 2014b):

- links to all the standard pipeline data models
- tools for positioning map windows
- support of non-numeric route IDs, such as GUIDs and strings
- modification of map series to include multiple map scales
- automatic management of text over-posting and leader lines

The PIEE offers all of these functions except for the last two. Multiple map scales, while infrequently used, could be useful and could be considered for inclusion in the PIEE at a future date and the final point of managing label placement automatically, is already identified for inclusion in a revised version of the PIEE. It was not included because of the effort involved and it was felt that the inclusion of other functionality, such as engineering and environmental, better demonstrated the value of the integrated system. At present, the labels are placed initially in the same relation to the point in the PIEE, with AutoCAD reactors attached to the label geometry, so that on moving the label the new location is stored for all future sheet generations.

8.2.7.8 *Summary*

The review of the functions available in seven existing proprietary systems compared to the PIEE are summarised in Table 8.5.

Functionality	System							
	EROI	SASG	BSDL	BSDS	EMTR	NCSHCA	NCSS	PIEE
GIS interface	✓		✓		✓	✓	✓	✓
CAD interface		✓		✓				✓
Automated route selection	✓							
Perform engineering functions/calculations						✓		✓
Perform preliminary pipeline hydraulic analysis								✓
Perform environmental engineering analysis								✓
Generate alignment sheets		✓	✓	✓	✓		✓	✓
Integrated template design		✓		✓	✓			✓
External template design			✓				✓	

Table 8.5 – System Functionality Matrix

8.3 Discussion

Early on in the design phase, the use of the integrated pipeline hydraulic analysis functionality has enabled the hydraulic engineer to perform route comparisons in order to help identify the optimum route from a hydraulic perspective. Similarly, the initial SERA has enabled the environmental engineer to evaluate route options, and so help to create a route that minimises the environmental impact due to soil erosion. In addition to the ability to perform a desktop analysis of the soil erosion risk, it enabled subsequent field verification to be more targeted through the identification of potential areas of concern.

From an engineering design perspective, it has had a major impact on previous methods. During the initial design phase, it has enabled the production of the majority of the pipeline design drawings, and so delivered significant improvements in terms of both quality and performance. Because of the improved performance, it has been viable to produce drawing types not previously created, thereby facilitating specific engineering and environmental design activities – for example, the reinstatement assessment drawings. In addition to facilitating the field evaluation of the route, they have enabled the environmental engineer to refine and improve the modelling process. By producing drawings that show the estimated

values for the components of the USLE, the engineer is able to compare these to field observations and enable refinements to the modelling process to be identified.

This Chapter has evaluated the PIEE against a range of design science methods. From the perspective of the PIEE being an artefact to demonstrate the constructs, models and methods of the thesis, the system has sufficient breadth and evaluation to demonstrate the validity of the approach and its application to pipeline design. Clearly further testing would be beneficial and to some extent, further development will enable additional evaluation, as in the case of the field study. The measure of the success of this thesis lies in its meeting the research objectives and key performance indicators defined at the outset, and in its making a contribution to knowledge. This contribution to knowledge is addressed in the final Chapter.

Chapter 9

CONCLUSIONS AND FURTHER WORK

The final chapter provides a précis of the thesis. The importance of the research and its place within the fields of pipeline engineering, environmental engineering and engineering design are discussed, as is the selected methodology and its suitability for the research approach. The main findings of the thesis and their contribution to knowledge are presented and linked to the research objectives and KPIs, set out in the thesis statement (Chapter 2). The implications and limitations of the current research are discussed and areas for future work identified.

9.1 Research Review and Findings

Although pipeline engineering is not a new field, there have been significant changes to the working practices over the last twenty-five years; CAE, CAD and, more recently, GIS have emerged to be increasingly dominant systems in the design of pipelines. With the advent of these computer-based systems, client expectations have risen. Whereas the duration of the design phase has reduced, there has been an increase in the level of engineering required as the focus on environmental, social and integrity management increases.

With an increasing global requirement for energy, the need to be able to transport fluids over long distances through hostile environments efficiently, safely and economically is greater than ever before. In addition, there is an increasing legislative requirement for pipeline operators to ensure that their systems meet the highest standards of integrity management. This includes the use of centralised, computer-based systems to manage the maintenance and integrity management of the pipeline; a prerequisite for successful PIM is the need for quality as-built data. Given these issues, the research question was defined as follows:

What are the design challenges for long onshore pipelines and how can the design process be modified to improve the quality of the engineering, environmental, design and as-built data, while reducing the cost and schedule impacts?

By reviewing the current methods for the design of pipelines, a research scope was defined which provided the constraints to the research question and formed the basis for the preliminary literature surveys. These identified the main challenges for the design of major onshore pipelines, which fell into three main categories: pipeline engineering, environmental engineering, and engineering design. These categories have been used as the basic chapter structure for the thesis. The literature surveys verified the validity of the research question and identified the framework for the subsequent detailed literature reviews.

During the course of the initial literature surveys, some significant absences (Rugg and Petre, 2004: 255) within the literature were identified. Fundamental to the thesis was the absence of research into the use and development of integrated engineering geographical information systems across engineering disciplines. Given the absence of a definition for these systems, the term AEGIS was defined with the aim of the research being established as follows:

The aim of this research is to develop a multi-disciplinary system for the design of onshore pipelines and to evaluate the effectiveness of this approach compared to current methods.

The aim, together with the results of the literature surveys, defined nine research objectives from which six KPIs were identified:

- 1. reduction in the number of interfaces, both software and discipline*
- 2. improved data interoperability*
- 3. ability to perform high-level pipeline hydraulics within a GIS system*
- 4. an improved method for the determination of the location classes for onshore gas pipelines that is more efficient, is repeatable, and enables the engineer to identify the impact of different code requirements*
- 5. reduction in the environmental impact of the project through early consideration of the soil erosion risk and potential bio-restoration strategies for the pipeline*
- 6. improved accuracy and speed of production of the alignment sheets and other design documents, including the production of as-built documentation*

While the KPIs provide metrics for the evaluation of the system in order to determine the success or otherwise of the artefact, and therefore of the research, the success of the thesis is in part based on its originality and its contribution to knowledge. Demonstrating the contribution to knowledge can be subjective; however, the publication of peer-reviewed papers arising out of the research is generally regarded as indicative that the contribution has wider merit (Tinkler and Jackson, 2004: 118) (QAA, 2011: 22).

The first of the research objectives (**Research Objective 1**) was to develop the research methodology for the thesis. Given the aim of the thesis, a design science approach was adopted as the most appropriate method with the development of the system as an artefact being central to proving its constructs, models and methods; this approach also provided a method for the evaluation of the system. From the literature survey, key components for the system were identified as requiring further research in order to develop them for inclusion within the AEGIS.

Another significant absence from the initial pipeline engineering literature survey was the inability for existing GIS-based pipeline routing applications to perform pipeline hydraulic analysis, a fundamental requirement of the pipeline design and routing processes. In order to support the inclusion of pipeline hydraulics within the AEGIS, a thorough review of the existing explicit equations for determining the friction factor across a wide range of Reynolds numbers and relative pipe roughness values was carried out.

Section 4.1 (**Research Objective 2a & KPI 3**) presented a review of 28 explicit equations for approximating the values obtained by the implicit Colebrook-White equation across a wide range of Reynolds numbers and relative pipe roughness values. This review (Winning and Coole, 2013) offers significant benefits over previous reviews (Brkić, 2011, Genić et al., 2011, Goudar and Sonnad, 2007, Goudar and Sonnad, 2008, Gregory and Fogarasi, 1985, Yildirim, 2009, Zigrang and Sylvester, 1985). It presents the accuracy obtained by the explicit equations in terms of both the MSE and the mean relative percentage error, enabling comparisons to be made with previous reviews. In addition to determining the accuracy of the equations, it also determines the computational efficiency. The previous reviews, which considered the complexity or efficiency for the explicit equations, did so either by reference to the number of algebraic notation calculator key strokes (Brkić, 2011, Zigrang and Sylvester, 1985) or by statistical modelling (Genić et al., 2011).

This research determined the relative computational efficiency for the explicit equations by comparing the time taken to perform the equations. This provides a more practical method of determining the relative computational efficiency. Finally, in this review, 2D and 3D contour plots were generated, which show the relative percentage error against all the combinations of Reynolds numbers and relative pipe roughness values for each explicit equation. The contour plots allow the engineer to identify the applicable range for each equation from the vast number of underlying calculations. The value of the contour plots for identifying the applicable ranges for explicit friction factor equations is evident as it is now being used by others (Brkić, 2014), who cite the paper published from this research in *Flow, Turbulence and Combustion* (Winning and Coole, 2013).

Based on the previous research, Section 4.2 (**Research Objective 2b & KPI 3**) proposed a new simplified explicit equation for the estimation of the friction factor for single-phase Newtonian fluids with improved computational efficiency. The improvement in computational efficiency is gained by recognising that most pipeline systems have few changes in pipe diameter against length and that by performing part of the calculation only on the change of pipe diameter reduces the computational overhead. This is achieved with constants within the new equation that are dependent on the relative pipe roughness and pipe diameter. When ranked by either the MSE or mean relative percentage error combined with the computational efficiency, the new equation was ranked first. Given the number of times that the friction factor needs to be calculated in the hydraulic simulation, this approach makes it possible to perform fast preliminary hydraulic calculations. The outcome of this

research was published in the *International Journal of Numerical Methods for Heat & Fluid Flow* (Winning and Coole, 2015).

In section 4.3, the method of determining the design factor for gas pipelines based on population density according to the ASME B31.8 standard is presented – a good example of a geospatial engineering problem (**Research Objective 2c & KPI 4**). Chapter 7 details the GIS approach used to determine the location class according to the code requirements. This CGI approach of providing engineers with geospatial tools within the CAD environment that they are familiar with was presented at the ESRI European Petroleum User Group Conference in London (Winning, 2014a).

In order to demonstrate the advantages of a multi-disciplinary approach to pipeline design, an element of environmental engineering was incorporated into the AEGIS (**Research Objective 2d & KPI 5**). In chapter 5, the use of remote sensed data to undertake a preliminary SERA was described. Although the application of the method was novel, the value of this approach is supported within the field (Morgan, 2005: 89). The research showed that, almost 70% of the route studied agreed with the SERA determined by field assessment with just over 96% being within a difference of ± 1 erosion class. The environmental impact of soil loss from major infrastructure projects was highlighted in the paper presented at the Uganda Investment Forum in Kampala (Winning, 2013a); and the use of remote sensed data for the SERA for pipelines was published in *Biosystems Engineering* (Winning and Hann, 2014) and presented at the ESRI European User Conference in Split (Winning, 2014b).

Chapter 6 looked at the issues of the use of open data standards and data interoperability (**Research Objective 2e & KPI 1, KPI 2**) and the challenges of CGI (**Research Objective 2f & KPI 1, KPI 2**). From an engineering design perspective, the challenges for the AEGIS involved the automated production of a large number of pipeline deliverable drawings, including route maps, strip maps, alignment sheets and crossing details (Appendix E). In addition to the drawings, the system had to be able to generate the various schedules and MTOs. It was also necessary to ensure that the data and deliverables were revision controlled. In order to support an improved method for the production of the as-built documentation for the subsequent operation and integrity management of the pipeline, the AEGIS needed to be compatible with existing complex pipeline specific data models. The novel application of a modified version of the PODS database schema to the CAD environment as part of the AEGIS was presented at the PODS User Conference in Houston

(Winning, 2014c). The wider issues of data interoperability and the challenges of CGI were addressed in a paper delivered at the ESRI European Petroleum User Group Conference in London (Winning, 2014a).

Based on this research, a SDS was developed (Appendix E) to enable the development of the system (**Research Objective 3 & KPI 1 to 6**). This document outlines the detailed design of an instantiation of an AEGIS called PIEE, including UML class diagrams, flowcharts for the methods, and a data dictionary for the properties. Although the instantiation of the AEGIS is called PIEE, reference to the system will be to the generic AEGIS because the system has been developed to demonstrate the constructs of the AEGIS and to avoid confusion.

Chapter 7 discusses the development of the AEGIS (**Research Objective 4 & KPI 1 to 6**). Using the SDS, the system was developed in Visual LISP using an object orientated programming approach. Abstract and core feature classes are defined in the SDS, with the user able to create new feature classes in order to support project specific requirements. The method used to create these new feature classes ensures that they are created in compliance with the abstract class requirements of the system.

Chapter 8 discusses the evaluation of the AEGIS (**Research Objective 4 & KPI 1 to 6**). The evaluation of the system was both quantitative and qualitative. In addition to evaluating the system using design science criteria, the system was evaluated against the KPIs defined at the outset of the research. The system has also been used on a major pipeline project of almost 500 kilometres, enabling a thorough evaluation of the system to be conducted and real metrics to be determined for its performance.

9.2 Limitations of the Research

As stated in the thesis statement, the system has been designed to demonstrate and prove the validity of the method rather than to develop a complete or commercially viable software application. Nevertheless, there are some potential limitations to the research, which may be summarised as follows:

- the use of other codes for the determination of population density
- limited validation of the approach of soil erosion risk assessment
- evaluation limited to a single project
- the issues of porting to other CAD systems

- detailed comparison to existing systems

While the ability to use other national codes for the determination of the design factor due to population density for gas pipelines would be useful, the application of the ASME B31.8 code clearly demonstrates the validity of the approach. It provides a robust quick repeatable determination for any route alignment. In doing so it is providing GIS functionality to the wider community of pipeline engineers, thereby enabling them to optimise the route and perform what-if scenarios on different routes. Perhaps more importantly, it enables a much more quantifiable approach to the allowance of additional heavy wall pipe for estimated population growth; this is an important consideration because it can add significant additional cost to the design for large diameter pipelines.

Possibly of greater concern is the limited validation of the estimated soil erosion to a 450km route corridor. Although the route provided a wide range of climatic conditions, elevation and soil types, there is still scope for further validation. This limitation was acknowledged in the conclusion of the paper (Winning and Hann, 2014), with a statement that further validation would be needed in the case of areas where there was a significant difference in the climatic or soil conditions, to those encountered in the study.

The third limitation is that of the evaluation of the AEGIS to a single project, which is a function of time available, and access to other new projects.

The fourth limitation is that although the initial aim was to produce, a system that could be ported to any CAD system, demonstrating this is impractical due to time constraints and is of little perceived value given that the environment that this was written in only uses AutoCAD.

The final limitation is that a detailed comparison to existing systems is not possible due to the budgetary constraints of the research. The cost of a single licence for these systems is in the order of \$5000 and therefore beyond the scope of this research. Therefore, it has been necessary to confine the comparison to feature level based on the specifications available in the public domain for these systems.

The first limitation could be addressed by the inclusion of additional code to determine the design factor for gas pipelines due to population density, though, as discussed, this is a limitation with respect to function rather than methodology. The question of further validation for the estimation of the soil erosion loss will be addressed over time as additional field investigations are undertaken for new pipeline corridors and this information is used to

further refine and validate the proposed method; this could result in the publication of a technical note as an addendum to the original paper. Likewise, it is envisaged that the use of the system on other projects will both help to refine and enhance the AEGIS and provide a more robust validation of the system. The limitation of cross platform support will only be significant if there is a requirement for this functionality. Moreover, the system has been designed as an open system; and with the SDS and the existing code acting as a means of validation, the porting of the code across to other platforms should not be a major problem – though it is acknowledged that it will take time.

9.3 Research Implications

There have been a number of unexpected benefits of the use of the AEGIS for pipeline design as the SCPX project testifies. With the automated method of producing the alignment sheets having significantly reduced the time required for both the production and the checking of these crucial project deliverables, it has become possible to develop different versions of the alignment sheets. These drawings are based on the traditional engineering alignment sheet, but modified to enable the creation of the following additional drawings (Appendix E):

- **Reinstatement assessment drawings:** These show the estimated values for the USLE, the estimated rate of soil loss, and provide space for recording field notes as part of the SERA.
- **Environmental alignment sheets:** By reducing the amount of engineering information, these drawings can contain additional environmental information.
- **Cadastral alignment sheets:** These allow the information relating to land owners and occupiers to be shown, such as area for compensation determination and the length of the permanent easement.

Possibly one of the single most important aspects of the AEGIS is the approach to the collection, validation of as-built data and the creation of the as-built alignment sheets. Prior to this research, the established method for the production of the as-built alignment sheets was for the installation contractor to supply these on mechanical completion. This method suffered from the drawback that the installation contractor was paid relatively little for these key documents and so had little incentive to ensure the timely delivery of a set of quality

documents. With the legislative requirements for integrity management, which came into effect in 2002, the importance of quality as-built data is as important to the pipeline operator as the commissioned pipeline.

The method employed by the AEGIS is to obtain all the contractors, as-built data in a tabular format that can be agreed with the contractor to minimise the data overhead. This is then imported into the system through code and linked to the material properties supplied by the vendor. From this a preliminary as-built alignment sheet is produced showing the installed centreline, the final design route and markers for all the agreed site change requests raised during the construction of the pipeline. These preliminary drawings also contain all the weld locations and identifiers and all fittings and valves on the pipeline. These drawings can be produced within hours of the data receipt for checking by both the site engineer and the construction contractor's field engineer. Once this drawing is accepted and signed off, the drawing is updated by the construction contractor with all the remaining as-built information such as pipeline and aerial marker locations, CP test posts and any remedial reinstatement measures. This data is then incorporated into the AEGIS and the final as-built drawings are issued. The value of this approach is in its recognising that as-built data has different levels of importance to the integrity management of the system. By concentrating on this key information and getting a fast turnaround, it is possible to check the validity and integrity of this key data.

9.4 Further Work

Although the AEGIS has been developed sufficiently to demonstrate the validity of the thesis, it could be further developed to provide a commercially viable software solution for the design of pipelines.

The preliminary hydraulic modelling functionality could be extended to include the ability to refine the model by modifying some of the station locations and fixing them so that the system could recalculate and balance the system with respect to fixed station locations. It would also be of value to investigate if the preliminary hydraulic model could be exported to support the subsequent hydraulic analysis in proprietary software such as PipeFlow and SPS.

Regarding the hydraulic analysis, work has already been started on an improved and automated generation of the ground temperature profile from GIS data. This would enable the AEGIS to recalculate the ground profile temperature for the line route dynamically. This method uses the global climate 30 arc second dataset (Hijmans et al., 2005) and will provide

a more accurate input to both the internal and external hydraulic modelling. The aim is to publish this research, which is rooted in the GIS field, in a pipeline-specific journal in order to publicise this improved method among hydraulic engineers, who are unlikely to read GIS journals. This approach is similar to that adopted for the dissemination of the GIS based method for the estimation of soil loss. In addition, consideration could be given to refine the location of pump/compressor stations.

For pump stations, a minimum required inlet head could be calculated to avoid any cavitation issues. Assuming the type of pump to be used is known and typical pump curves along with a rough estimation of the Net Positive Suction Head Required (NPSHr) is available, a minimum inlet head can be calculated. This could be achieved by calculating the Net Positive Suction Head Available (NPSHa) and comparing it to the NPSHr. If the NPSHa is greater than or equal to the NPSHr, then the available pump inlet head available at the location of the pump is sufficient to ensure the pump can operate with any risk of cavitation. However, if the NPSHa were found to be lower than the NPSHr then the pump location would be moved further upstream, until the NPSHa was greater than or equal to the NPSHr.

A similar refinement on the location of compressor stations could be carried out by limiting the compression ratio to a maximum value between 2 to 2.5 – as it is not practical to compress the fluid by much more than twice the inlet pressure. If the compression ratio was calculated at more than 2 to 2.5 then the compressor station location could be moved upstream until it satisfies this requirement.

Another area for further development is the incorporation of basic cost modelling functionality to aid the pipeline engineer in the initial selection and ranking of potential route options. In addition to providing an internal basic cost modelling function, the ability to export the relevant data from the model for use in external cost modelling software would be beneficial. This would also enable the validation of the internal cost modelling method.

Although the system is already capable of producing the majority of the pipeline specific drawings required, it could be expanded to generate the pipeline typical drawings. This would be accomplished by using standard details with tabulated dimensions corresponding to the engineering details already stored within the model. This approach would further reduce interfaces and ensure consistency.

Finally, there is the possibility of optimising and selecting routes based on a form of surface cost model; this is clearly dependent on the availability of sufficient data and the right resolution to build the cost surface. This would be a two-phased approach. In the first instance, the optimisation module would be created, enabling the route to be optimised between set points. This would form the basis of the automated route selection function. It is realised that this is a longer term aspiration for the system, and might possibly be based on the Dijkstra algorithm (Chu and Chen, 2012).

There is potential for further developments in the AEGIS, and this research could offer benefits to the wider research community. As already mentioned, research is in progress, with a view to publication of an improved method for determining the ground temperature profile for hydraulic analysis of pipelines. In addition, it is intended that this thesis will form the basis for further journal papers on the application of pipeline hydraulics within the GIS environment and the use and development of AEGIS for pipelines.

9.5 Conclusion

In addition to fulfilling the research objectives, the development of the AEGIS has demonstrated a potential solution for the wider issue of CGI. Given the range of engineering disciplines to which GIS might be applicable, it is unreasonable to expect all but a few GIS practitioners to gain a thorough knowledge of the different engineering disciplines necessary to develop CGI solutions. If CGI is not to remain a collision zone indefinitely (Miller, 2004), it is incumbent on engineers to embrace GIS technology in order to develop CGI solutions.

This research has been challenging – in part due to its multi-disciplinary nature and the breadth of the scope, and the need to develop a functioning system capable of evaluating and demonstrating the validity of the approach. In creating the PIEE, approximately 12,000 lines of code have been written, supported by 18,000 lines of code in the acLib library functions.

It has demonstrated the value of using an integrated, cross-discipline functional approach to the design of onshore pipelines. This has reduced design times, interfaces and costs while improving productivity, data interoperability and quality. Not only has it improved the design, it has also enabled a new approach to the collection and production of as-built data, which is critical to the safe and efficient management of the pipeline asset throughout its operational life.

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APPENDICES

Appendix A – Review of Explicit Friction Factor Equations

Appendix A1 – Reviewed Equations

$$f_f = 1.375 \times 10^{-3} \left[1 + \left(2 \times 10^4 \frac{\varepsilon}{D} + \frac{10^6}{\text{Re}} \right)^{\frac{1}{3}} \right] \quad (\text{Eq. A1.1})$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 0 \leq 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Zigrang and Sylvester, 1985),

(Goudar and Sonnad, 2007), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.1 (Moody, 1947)

$$f_d = 0.11 \left(\frac{68}{\text{Re}} + \frac{\varepsilon}{D} \right)^{0.25} \quad (\text{Eq. A1.2})$$

No applicable ranges specified in the original paper.

Reviewed by:

(Genić et al., 2011)

Equation A1.2 Altshul 1952, cited in (Genić et al., 2011)

$$f_d = 0.094 \left(\frac{\varepsilon}{D} \right)^{0.225} + 0.53 \left(\frac{\varepsilon}{D} \right) + 88 \left(\frac{\varepsilon}{D} \right)^{0.4} \text{Re}^{-4} \quad (\text{Eq. A1.3})$$

Where

$$A_1 = 1.62 \left(\frac{\varepsilon}{D} \right)^{0.134}$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 5 \times 10^7$$

$$\frac{\varepsilon}{D} \geq 10^{-5} \leq 4 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Goudar and Sonnad, 2007), (Brkić, 2011),
(Genić et al., 2011)

Note:

In the (Gregory and Fogarasi, 1985) paper it was incorrectly identified as returning the Fanning friction factor, rather than the Darcy friction factor.

Equation A1.3 (Wood, 1966)

$$\frac{1}{\sqrt{f_d}} = -2 \log \left[\frac{\varepsilon}{3.7D} + \left(\frac{7}{\text{Re}} \right)^{0.9} \right] \quad (\text{Eq. A1.4})$$

No applicable ranges specified in the original paper.

Reviewed by:

(Goudar and Sonnad, 2007), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.4 (Churchill, 1973)

$$\frac{1}{\sqrt{f_d}} = -2 \log \left(\frac{\varepsilon}{3.715D} + \frac{15}{\text{Re}} \right) \quad (\text{Eq. A1.5})$$

No applicable ranges specified in the original paper.

Reviewed by:

(Brkić, 2011)

Equation A1.5 (Eck, 1954)

$$\frac{1}{\sqrt{f_f}} = 2.28 - 4 \log \left[\frac{\varepsilon}{D} + \left(\frac{29.843}{\text{Re}} \right)^{0.9} \right] \quad (\text{Eq. A1.6})$$

Applicable Range:

$$\text{Re} \geq 5 \times 10^3 \text{ and } \leq 10^7$$

$$\frac{\varepsilon}{D} \geq 4 \times 10^{-5} \leq 5 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Zigrang and Sylvester, 1985),

(Goudar and Sonnad, 2007), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.6 (Jain, 1976)

$$\frac{1}{\sqrt{f_f}} = -4 \log \left[\left(\frac{6.97}{\text{Re}} \right)^{0.9} + \left(\frac{\varepsilon}{3.7D} \right) \right] \quad (\text{Eq. A1.7})$$

Applicable Range:

$$\text{Re} \geq 5 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 10^{-6} \leq 5 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Goudar and Sonnad, 2007), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.7 (Swamee and Jain, 1976)

$$f_f = 2 \left[\left(\frac{8}{\text{Re}} \right)^{12} + \frac{1}{(A_2 + A_3)^2} \right]^{\frac{1}{12}} \quad (\text{Eq. A1.8})$$

Where

$$A_2 = \left\{ 2.457 \ln \left[\left(\frac{7}{\text{Re}} \right)^{0.9} + 0.27 \frac{\varepsilon}{D} \right] \right\}^{16}$$

$$A_3 = \left(\frac{37530}{\text{Re}} \right)^{16}$$

No applicable ranges specified in the original paper.

Reviewed by:

(Gregory and Fogarasi, 1985), (Yildirim, 2009), (Brkić, 2011)

Equation A1.8 (Churchill, 1977)

$$\frac{1}{\sqrt{f_f}} = -4 \log \left[\frac{\varepsilon}{3.7065D} - \frac{5.0452}{\text{Re}} \log A_4 \right] \quad (\text{Eq. A1.9})$$

Where

$$A_4 = \frac{(\varepsilon / D)^{1.1098}}{2.8257} + \left(\frac{7.149}{\text{Re}} \right)^{0.8981}$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 4 \times 10^8$$

$$\frac{\varepsilon}{D} \geq 10^{-7} \leq 5 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Zigrang and Sylvester, 1985),

(Goudar and Sonnad, 2008), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.9 (Chen, 1979)

$$\frac{1}{\sqrt{f_f}} = -3.6 \log \left[\frac{\text{Re}}{0.135 \text{Re} \left(\frac{\varepsilon}{D} \right) + 6.5} \right] \quad (\text{Eq. A1.10})$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 0 \leq 5 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Goudar and Sonnad, 2007), (Brkić, 2011),

(Genić et al., 2011)

Equation A1.10 (Round, 1980)

$$\frac{1}{\sqrt{f_f}} = -4 \log \left[\frac{\varepsilon}{3.7D} - \frac{5.02}{\text{Re}} \log \left(\frac{\varepsilon}{3.7D} + \frac{14.5}{\text{Re}} \right) \right] \quad (\text{Eq. A1.11})$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 4 \times 10^8$$

Reviewed by:

(Zigrang and Sylvester, 1985)

Equation A1.11 (Shacham, 1980)

$$\frac{1}{\sqrt{f_d}} = -2 \log \left\{ \frac{\varepsilon}{3.7D} + \frac{4.518 \log \left(\frac{\text{Re}}{7} \right)}{\text{Re} \left[1 + \left(\frac{\text{Re}^{0.52}}{29} \right) \left(\frac{\varepsilon}{D} \right)^{0.7} \right]} \right\} \quad (\text{Eq. A1.12})$$

No applicable ranges specified in the original paper.

Reviewed by:

(Goudar and Sonnad, 2008), (Yildirim, 2009), (Brkić, 2011)

Equation A1.12 (Barr, 1981)

$$\frac{1}{\sqrt{f_f}} = -4 \log \left[\frac{\varepsilon}{3.7D} - \frac{5.02}{\text{Re}} \log A_5 \right] \quad (\text{Eq. A1.13})$$

Where

$$A_5 = \frac{e}{3.7D} + \frac{13}{\text{Re}}$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 4 \times 10^{-5} \leq 5 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Zigrang and Sylvester, 1985),

(Goudar and Sonnad, 2008), (Brkić, 2011)

Equation A1.13 (Zigrang and Sylvester, 1982 - Eq. 11)

$$\frac{1}{\sqrt{f_f}} = -4 \log \left[\frac{\varepsilon}{3.7D} - \frac{5.02}{\text{Re}} \log A_6 \right] \quad (\text{Eq. A1.14})$$

Where

$$A_5 = \frac{e}{3.7D} + \frac{13}{\text{Re}}$$

$$A_6 = \frac{e}{3.7D} - \frac{5.02}{\text{Re}} \log A_5$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 4 \times 10^{-5} \leq 5 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Goudar and Sonnad, 2008), (Yildirim, 2009),
(Brkić, 2011), (Genić et al., 2011)

Notes:

This equation was incorrectly stated in the (Gregory and Fogarasi, 1985) paper, where the equation was given as:

$$\frac{1}{\sqrt{f_f}} = -4 \log \left[\frac{\varepsilon}{3.7D} - 5.02 \log A_6 \right]$$

Equation A1.14 (Zigrang and Sylvester, 1982 - Eq. 12)

$$\frac{1}{\sqrt{f_f}} = -3.6 \log \left[\frac{6.9}{\text{Re}} + \left(\frac{\varepsilon}{3.7D} \right)^{1.11} \right] \quad (\text{Eq. A1.15})$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 10^{-6} \leq 5 \times 10^{-2}$$

Reviewed by:

(Gregory and Fogarasi, 1985), (Zigrang and Sylvester, 1985),

(Goudar and Sonnad, 2007), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.15 (Haaland, 1983)

$$f_d = \left[A_7 - \frac{(A_8 - A_7)^2}{A_9 - 2A_8 + A_7} \right]^{-2} \quad (\text{Eq. A1.16})$$

Where

$$A_7 = -2 \log \left(\frac{\varepsilon}{3.7D} + \frac{12}{\text{Re}} \right)$$

$$A_8 = -2 \log \left(\frac{\varepsilon}{3.7D} + \frac{2.51A_7}{\text{Re}} \right)$$

$$A_9 = -2 \log \left(\frac{\varepsilon}{3.7D} + \frac{2.51A_8}{\text{Re}} \right)$$

No applicable ranges specified in the original paper.

Reviewed by:

(Gregory and Fogarasi, 1985), (Zigrang and Sylvester, 1985),

(Goudar and Sonnad, 2008), (Brkić, 2011)

Note:

In the (Gregory and Fogarasi, 1985) paper it was incorrectly identified as returning the Fanning friction factor, rather than the Darcy friction factor.

Equation A1.16 (Serghides, 1984 - Eq. 2)

$$f_d = \left[4.781 - \frac{(A_7 - 4.781)^2}{A_8 - 2A_7 + 4.781} \right]^{-2} \quad (\text{Eq. A1.17})$$

Where

$$A_7 = -2 \log \left(\frac{\varepsilon}{3.7D} + \frac{12}{\text{Re}} \right)$$

$$A_8 = -2 \log \left(\frac{\varepsilon}{3.7D} + \frac{2.51A_7}{\text{Re}} \right)$$

No applicable ranges specified in the original paper.

Reviewed by:

(Gregory and Fogarasi, 1985), (Goudar and Sonnad, 2008), (Brkić, 2011)

Note:

In the (Gregory and Fogarasi, 1985) paper it was incorrectly identified as returning the Fanning friction factor, rather than the Darcy friction factor.

Equation A1.17 (Serghides, 1984 - Eq. 3)

$$A = 0.11 \left(\frac{68}{\text{Re}} + \frac{\varepsilon}{D} \right)^{0.25} \quad (\text{Eq. A1.18})$$

if $A \geq 0.018$ then $f_d = A$

if $A < 0.018$ then $f_d = 0.0028 + 0.85A$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 0 \leq 5 \times 10^{-2}$$

Reviewed by:

(Genić et al., 2011)

Equation A1.18 (Tsal, 1989)

$$\frac{1}{\sqrt{f_d}} = -2 \log \left[\left(\frac{\varepsilon}{3.7D} \right) + \left(\frac{95}{\text{Re}^{0.983}} \right) - \left(\frac{96.82}{\text{Re}} \right) \right] \quad (\text{Eq. A1.19})$$

Applicable Range:

$$\text{Re} \geq 5.235 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 0 \leq 5 \times 10^{-2}$$

Reviewed by:

(Goudar and Sonnad, 2007), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.19 (Manadilli, 1997)

$$\frac{1}{\sqrt{f_d}} = -2 \log \left\{ \frac{\varepsilon}{3.7065D} \times \frac{5.0272}{\text{Re}} \times \log \left[\frac{\varepsilon}{3.827D} - \frac{4.567}{\text{Re}} \times \log \left(\left(\frac{\varepsilon}{7.7918D} \right)^{0.9924} + \left(\frac{5.3326}{208.815 + \text{Re}} \right)^{0.9345} \right) \right] \right\} \quad (\text{Eq. A1.20})$$

Applicable Range:

$$\text{Re} \geq 3 \times 10^3 \text{ and } \leq 1.5 \times 10^8$$

$$\frac{\varepsilon}{D} \geq 0 \leq 5 \times 10^{-2}$$

Reviewed by:

(Goudar and Sonnad, 2008), (Yildirim, 2009), (Brkić, 2011), (Genić et al., 2011)

Equation A1.20 (Romeo et al., 2002)

$$\frac{1}{\sqrt{f_d}} = 0.8686 \ln \left(\frac{0.4587 \text{ Re}}{S^{(S/S+1)}} \right) \quad (\text{Eq. A1.21})$$

Where

$$S = 0.1240 \times \frac{\varepsilon}{D} \times \text{Re} + \ln(0.4587 \text{ Re})$$

Applicable Range:

$$\text{Re} \geq 4 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 10^{-6} \leq 5 \times 10^{-2}$$

Reviewed by:

(Goudar and Sonnad, 2007), (Yildirim, 2009), (Brkić, 2011)

Equation A1.21 (Sonnad and Goudar, 2006)

$$\frac{1}{\sqrt{f_d}} = 2 \log \left(\frac{\left(2 \frac{\varepsilon}{D} \right)^{-1}}{\left(\frac{0.444 + 0.135 \text{ Re}}{\text{Re}} \right) \beta} \right) \quad (\text{Eq. A1.22})$$

Where

$$\beta = 1 - 0.55 e^{-0.33 \left[\ln \left(\frac{\text{Re}}{6.5} \right) \right]^2}$$

No applicable ranges specified in the original paper.

Reviewed by:

(Brkić, 2011)

Equation A1.22 (Rao and Kumar, 2006)

$$\frac{1}{\sqrt{f_d}} = B_1 - \left[\frac{B_1 + 2 \log \left(\frac{B_2}{\text{Re}} \right)}{1 + \frac{2.18}{B_2}} \right] \quad (\text{Eq. A1.23})$$

Where

$$B_1 = \frac{[0.774 \ln(\text{Re})] - 1.41}{\left(1 + 1.32 \sqrt{\frac{\varepsilon}{D}} \right)}$$

$$B_2 = \frac{\varepsilon}{3.7D} \times \text{Re} + 2.51 \times B_1$$

No applicable ranges specified in the original paper.

Reviewed by:

(Brkić, 2011)

Equation A1.23 (Buzzelli, 2008)

$$f_d = \frac{6.4}{\left\{ \ln(\text{Re}) - \ln \left[1 + 0.01 \text{Re} \times \frac{\varepsilon}{D} \times \left(1 + 10 \times \sqrt{\frac{\varepsilon}{D}} \right) \right] \right\}^{2.4}} \quad (\text{Eq. A1.24})$$

No applicable ranges specified in the original paper.

Reviewed by:

(Brkić, 2011)

Equation A1.24 (Avci and Karagoz, 2009)

$$f_d = \frac{0.2479 - 0.0000947 \times (7 - \log \text{Re})^4}{\left[\log \left(\frac{\varepsilon}{3.615D} + \frac{7.366}{\text{Re}^{0.9142}} \right) \right]^2} \quad (\text{Eq. A1.25})$$

Applicable Range:

$$\text{Re} \geq 10^4 \text{ and } \leq 10^7$$

$$\frac{\varepsilon}{D} \geq 10^{-5} \leq 10^{-3}$$

Reviewed by:

(Brkić, 2011)

Equation A1.25 (Papaevangelou et al., 2010)

$$f_d = \left[-2 \log \left(10^{-0.4343\beta} + \frac{\varepsilon}{3.71D} \right) \right]^{-2} \quad (\text{Eq. A1.26})$$

Where

$$\beta = \ln \frac{\text{Re}}{1.816 \ln \left(\frac{1.1 \text{Re}}{\ln(1 + 1.1 \text{Re})} \right)}$$

No applicable ranges specified in the original paper.

Reviewed by:

(Genić et al., 2011)

Equation A1.26 (Brkić, 2011 - Eq. A)

$$f_d = \left[-2 \log \left(\frac{2.18\beta}{\text{Re}} + \frac{\varepsilon}{3.71D} \right) \right]^{-2} \quad (\text{Eq. A1.27})$$

Where

$$\beta = \ln \frac{\text{Re}}{1.816 \ln \left(\frac{1.1 \text{Re}}{\ln(1 + 1.1 \text{Re})} \right)}$$

No applicable ranges specified in the original paper.

Reviewed by:

(Genić et al., 2011)

Equation A1.27 (Brkić, 2011 - Eq. B)

$$f_d = 1.613 \left\{ \ln \left[0.234 \left(\frac{\varepsilon}{D} \right)^{1.1007} - \frac{60.525}{\text{Re}^{1.1105}} + \frac{56.291}{\text{Re}^{1.0712}} \right] \right\}^{-2} \quad (\text{Eq. A1.28})$$

Applicable Range:

$$\text{Re} \geq 3 \times 10^3 \text{ and } \leq 10^8$$

$$\frac{\varepsilon}{D} \geq 0 \leq 5 \times 10^{-2}$$

Reviewed by:

(Genić et al., 2011)

Equation A1.28 (Fang et al., 2011)

Appendix A2 – Tables

Equation	Absolute Error			Relative Percentage Error		
	Min	Max	Mean	Min	Max	Mean
(Eq. A1.23) (Buzzelli, 2008)	1.139E-12	9.401E-06	1.224E-06	3.547E-09	2.355E-02	0.005
(Eq. A1.16) (Serghides, 1984 - Eq. 2)	2.096E-12	9.467E-06	1.491E-06	4.309E-09	2.372E-02	0.006
(Eq. A1.14) (Zigrang and Sylvester, 1982 - Eq. 12)	2.096E-12	3.051E-05	4.027E-06	4.309E-09	1.305E-01	0.019
(Eq. A1.17) (Serghides, 1984 - Eq. 3)	2.095E-12	4.697E-05	6.668E-06	4.308E-09	3.680E-01	0.037
(Eq. A1.20) (Romeo et al., 2002)	2.566E-09	9.877E-05	2.528E-05	2.730E-05	1.226E-01	0.057
(Eq. A1.12) (Barr, 1981)	4.175E-11	2.588E-04	2.315E-05	3.180E-07	5.533E-01	0.063
(Eq. A1.9) (Chen, 1979)	3.493E-09	1.537E-04	3.388E-05	2.902E-05	3.387E-01	0.097
(Eq. A1.11) (Shacham, 1980)	1.738E-13	3.557E-04	2.941E-05	3.573E-10	8.912E-01	0.125
(Eq. A1.13) (Zigrang and Sylvester, 1982 - Eq. 11)	1.098E-12	1.866E-04	2.790E-05	2.258E-09	9.921E-01	0.141
(Eq. A1.28) (Fang et al., 2011)	5.795E-09	5.534E-04	5.412E-05	4.616E-05	5.347E-01	0.156
(Eq. A1.21) (Sonnad and Goudar, 2006)	1.285E-07	3.867E-04	5.222E-05	1.344E-03	9.688E-01	0.174
(Eq. A1.25) (Papaevangelou et al., 2010)	5.746E-09	1.491E-03	1.020E-04	3.273E-05	1.411E+00	0.230
(Eq. A1.15) (Haaland, 1983)	2.700E-08	9.734E-04	1.191E-04	1.675E-04	1.434E+00	0.373
(Eq. A1.19) (Manadilli, 1997)	6.875E-09	2.484E-03	1.561E-04	3.636E-05	2.710E+00	0.393
(Eq. A1.6) (Jain, 1976)	3.229E-09	2.533E-03	1.803E-04	1.642E-05	3.172E+00	0.452
(Eq. A1.8) (Churchill, 1977)	2.028E-09	1.723E-02	1.856E-04	1.089E-05	1.631E+01	0.475
(Eq. A1.7) (Swamee and Jain, 1976)	6.917E-08	2.786E-03	1.838E-04	1.769E-04	3.343E+00	0.478
(Eq. A1.27) (Brkić, 2011 - Eq. B)	1.058E-09	2.445E-03	1.850E-04	5.678E-06	2.799E+00	0.479
(Eq. A1.4) (Churchill, 1973)	1.142E-08	2.812E-03	1.891E-04	1.046E-04	3.407E+00	0.492
(Eq. A1.26) (Brkić, 2011 - Eq. A)	1.105E-09	1.723E-03	2.187E-04	1.364E-05	3.396E+00	0.721
(Eq. A1.5) (Eck, 1954)	6.901E-08	3.506E-03	3.899E-04	1.265E-04	8.209E+00	1.503
(Eq. A1.24) (Avci and Karagoz, 2009)	2.940E-08	6.184E-03	9.576E-04	1.398E-04	6.084E+00	1.716
(Eq. A1.3) (Wood, 1966)	2.265E-07	1.128E-02	1.536E-03	1.859E-03	2.825E+01	3.876
(Eq. A1.10) (Round, 1980)	1.573E-07	1.336E-02	2.260E-03	8.530E-04	1.315E+01	4.474
(Eq. A1.1) (Moody, 1947)	3.629E-08	2.809E-02	3.962E-03	2.869E-04	2.658E+01	6.098
(Eq. A1.18) (Tsal, 1989)	2.689E-09	4.132E-02	6.435E-03	1.693E-05	3.915E+01	8.894
(Eq. A1.2) (Altshul 1952, cited in (Genić et al., 2011))	4.564E-08	4.132E-02	6.684E-03	2.187E-04	3.972E+01	11.449
(Eq. A1.22) (Rao and Kumar, 2006)	5.086E-06	3.412E-02	3.469E-03	2.838E-02	8.548E+01	13.270

Table A2.1 – Explicit Equations by Mean Relative Percentage Error

Application and Development of AEGIS for Pipeline Design

Equation	MSE	Magnitude of Error	Distribution
(Eq. A1.23) (Buzzelli, 2008)	5.622E-12	Very Small	Upper Diagonal
(Eq. A1.16) (Serghides, 1984 - Eq. 2)	7.511E-12	Very Small	Upper Diagonal
(Eq. A1.14) (Zigrang and Sylvester, 1982 - Eq. 12)	7.067E-11	Small	Upper Diagonal
(Eq. A1.17) (Serghides, 1984 - Eq. 3)	1.886E-10	Small	Upper Diagonal
(Eq. A1.20) (Romeo et al., 2002)	1.330E-09	Small	Diagonal Ridge
(Eq. A1.12) (Barr, 1981)	1.945E-09	Small	Upper Diagonal
(Eq. A1.9) (Chen, 1979)	2.032E-09	Small	Diagonal Ridge Error
(Eq. A1.13) (Zigrang and Sylvester, 1982 - Eq. 11)	3.101E-09	Small	Upper Diagonal
(Eq. A1.11) (Shacham, 1980)	3.834E-09	Small	Upper Diagonal
(Eq. A1.28) (Fang et al., 2011)	6.551E-09	Small	Unclassified
(Eq. A1.21) (Sonnad and Goudar, 2006)	1.053E-08	Medium	Upper Diagonal
(Eq. A1.15) (Haaland, 1983)	2.670E-08	Medium	Upper Diagonal
(Eq. A1.25) (Papaevangelou et al., 2010)	4.089E-08	Medium	Unclassified
(Eq. A1.19) (Manadilli, 1997)	1.277E-07	Medium	Diagonal Ridge Error
(Eq. A1.6) (Jain, 1976)	1.325E-07	Medium	Upper Diagonal
(Eq. A1.27) (Brkić, 2011 - Eq. B)	1.352E-07	Medium	Upper Diagonal
(Eq. A1.26) (Brkić, 2011 - Eq. A)	1.511E-07	Medium	Upper Diagonal
(Eq. A1.7) (Swamee and Jain, 1976)	1.606E-07	Medium	Upper Diagonal
(Eq. A1.4) (Churchill, 1973)	1.677E-07	Medium	Upper Diagonal
(Eq. A1.8) (Churchill, 1977)	2.185E-07	Medium	Upper Diagonal
(Eq. A1.5) (Eck, 1954)	4.640E-07	Medium	Upper Diagonal
(Eq. A1.24) (Avci and Karagoz, 2009)	3.353E-06	Medium	Unclassified
(Eq. A1.3) (Wood, 1966)	5.913E-06	Large	Unclassified
(Eq. A1.10) (Round, 1980)	1.835E-05	Large	Unclassified
(Eq. A1.22) (Rao and Kumar, 2006)	5.159E-05	Large	Upper Diagonal
(Eq. A1.1) (Moody, 1947)	7.142E-05	Large	Unclassified
(Eq. A1.18) (Tsal, 1989)	1.746E-04	Large	Unclassified
(Eq. A1.2) (Altshul 1952, cited in (Genić et al., 2011))	1.751E-04	Large	Unclassified

Table A2.2 – Explicit Equations by Mean Square Error

Equation	Relative Computational Efficiency				Rank
	Run 1	Run 2	Run 3	Mean	
(Eq. A1.2) Altshul 1952, cited in (Genić et al., 2011)	0.4773	0.4766	0.4779	0.4773	1
(Eq. A1.1) (Moody, 1947)	0.4926	0.4869	0.4881	0.4892	2
(Eq. A1.3) (Wood, 1966)	0.5284	0.5226	0.5239	0.5250	3
(Eq. A1.5) (Eck, 1954)	0.5539	0.5634	0.5597	0.5590	4
(Eq. A1.18) (Tsal, 1989)	0.5692	0.5685	0.5648	0.5675	5
(Eq. A1.10) (Round, 1980)	0.5795	0.5787	0.5802	0.5795	6
(Eq. A1.4) (Churchill, 1973)	0.5846	0.5787	0.5853	0.5829	7
(Eq. A1.7) (Swamee and Jain, 1976)	0.5948	0.5889	0.5955	0.5931	8
(Eq. A1.21) (Sonnad and Goudar, 2006)	0.5999	0.5940	0.6058	0.5999	9
(Eq. A1.6) (Jain, 1976)	0.6050	0.5991	0.6007	0.6016	10
(Eq. A1.8) (Churchill, 1977)	0.5999	0.6042	0.6078	0.6040	11
(Eq. A1.24) (Avci and Karagoz, 2009)	0.6173	0.6063	0.6129	0.6122	12
(Eq. A1.11) (Shacham, 1980)	0.6224	0.6216	0.6232	0.6224	13
(Eq. A1.15) (Haaland, 1983)	0.6377	0.6267	0.6334	0.6326	14
(Eq. A1.13) (Zigrang and Sylvester, 1982 - Eq. 11)	0.6326	0.6369	0.6334	0.6343	15
(Eq. A1.28) (Fang et al., 2011)	0.6429	0.6369	0.6437	0.6411	16
(Eq. A1.17) (Serghides, 1984 - Eq. 3)	0.6480	0.6420	0.6488	0.6463	17
(Eq. A1.19) (Manadilli, 1997)	0.6480	0.6471	0.6590	0.6514	18
(Eq. A1.9) (Chen, 1979)	0.6531	0.6522	0.6539	0.6531	19
(Eq. A1.16) (Serghides, 1984 - Eq. 2)	0.6633	0.6522	0.6590	0.6582	20
(Eq. A1.12) (Barr, 1981)	0.6633	0.6573	0.6641	0.6616	21
(Eq. A1.27) (Brkić, 2011 - Eq. B)	0.6735	0.6726	0.6743	0.6735	22
(Eq. A1.14) (Zigrang and Sylvester, 1982 - Eq. 12)	0.6786	0.6675	0.6743	0.6735	23
(Eq. A1.22) (Rao and Kumar, 2006)	0.6837	0.6828	0.6897	0.6854	24
(Eq. A1.23) (Buzzelli, 2008)	0.6939	0.6879	0.6948	0.6922	25
(Eq. A1.26) (Brkić, 2011 - Eq. A)	0.6939	0.6879	0.6999	0.6939	26
(Eq. A1.20) (Romeo et al., 2002)	0.7144	0.7083	0.7102	0.7110	27
(Eq. A1.25) (Papaevangelou et al., 2010)	0.7399	0.7390	0.7409	0.7399	28

Table A2.3 – Explicit Equations by Relative Computational Efficiency

Application and Development of AEGIS for Pipeline Design

Equation	Internal Iterations	Accuracy		Computational Efficiency		Combined Rank	
		MSE	Rank A	Relative Effort	Rank B	A + B	Rank C
(Eq. A1.21) (Sonnad and Goudar, 2006)	2	1.053E-08	11	0.5999	9	20	1
(Eq. A1.17) (Serghides, 1984 - Eq. 3)	3	1.886E-10	4	0.6463	17	21	2
(Eq. A1.16) (Serghides, 1984 - Eq. 2)	3	7.511E-12	2	0.6582	20	22	3
(Eq. A1.11) (Shacham, 1980)	2	3.834E-09	9	0.6224	13	22	4
(Eq. A1.13) (Zigrang and Sylvester, 1982 - Eq. 11)	2	3.101E-09	8	0.6343	15	23	5
(Eq. A1.6) (Jain, 1976)	1	1.325E-07	15	0.6016	10	25	6
(Eq. A1.5) (Eck, 1954)	1	4.640E-07	21	0.5590	4	25	7
(Eq. A1.23) (Buzzelli, 2008)	3	5.622E-12	1	0.6922	25	25	8
(Eq. A1.14) (Zigrang and Sylvester, 1982 - Eq. 12)	3	7.067E-11	3	0.6735	23	26	9
(Eq. A1.9) (Chen, 1979)	2	2.032E-09	7	0.6531	19	26	10
(Eq. A1.28) (Fang et al., 2011)	1	6.551E-09	10	0.6411	16	26	11
(Eq. A1.15) (Haaland, 1983)	1	2.670E-08	12	0.6326	14	26	12
(Eq. A1.7) (Swamee and Jain, 1976)	1	1.606E-07	18	0.5931	8	26	13
(Eq. A1.4) (Churchill, 1973)	1	1.677E-07	19	0.5829	7	26	14
(Eq. A1.3) (Wood, 1966)	0	5.913E-06	23	0.5250	3	26	15
(Eq. A1.12) (Barr, 1981)	2	1.945E-09	6	0.6616	21	27	16
(Eq. A1.1) (Moody, 1947)	0	7.142E-05	26	0.4892	2	28	17
(Eq. A1.2) (Altshul 1952, cited in (Genić et al., 2011))	0	1.751E-04	28	0.4773	1	29	18
(Eq. A1.10) (Round, 1980)	1	1.835E-05	24	0.5795	6	30	19
(Eq. A1.8) (Churchill, 1977)	1	2.185E-07	20	0.6040	11	31	20
(Eq. A1.20) (Romeo et al., 2002)	3	1.330E-09	5	0.7110	27	32	21
(Eq. A1.19) (Manadilli, 1997)	1	1.277E-07	14	0.6514	18	32	22
(Eq. A1.18) (Tsal, 1989)	0	1.746E-04	27	0.5675	5	32	23
(Eq. A1.24) (Avci and Karagoz, 2009)	2	3.353E-06	22	0.6122	12	34	24
(Eq. A1.27) (Brkić, 2011 - Eq. B)	4	1.352E-07	16	0.6735	22	38	25
(Eq. A1.25) (Papaevangelou et al., 2010)	2	4.089E-08	13	0.7399	28	41	26
(Eq. A1.26) (Brkić, 2011 - Eq. A)	4	1.511E-07	17	0.6939	26	43	27
(Eq. A1.22) (Rao and Kumar, 2006)	2	5.159E-05	25	0.6854	24	49	28

Table A2.4 – Explicit Equations by MSE and Computational Efficiency

Appendix A3 – 2D and 3D Contour Plots

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Figure A3.1 – Contour Plots (Moody, 1947)

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Figure A3.2 – Contour Plots Altshul 1952, cited in (Genić et al., 2011)

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Figure A3.3 – Contour Plots (Wood, 1966)

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Figure A3.4 – Contour Plots (Churchill, 1973)

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Figure A3.5 – Contour Plots (Eck, 1954)

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Figure A3.7 – Contour Plots (Swamee and Jain, 1976)

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Figure A3.8 – Contour Plots (Churchill, 1977)

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Figure A3.9 – Contour Plots (Chen, 1979)

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Figure A3.10 – Contour Plots (Round, 1980)

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Figure A3.11 – Contour Plots (Shacham, 1980)

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Figure A3.12 – Contour Plots (Barr, 1981)

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Figure A3.13 – Contour Plots (Zigrang and Sylvester, 1982 - Eq. 11)

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Figure A3.14 – Contour Plots (Zigrang and Sylvester, 1982 - Eq. 12)

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Figure A3.15 – Contour Plots (Haaland, 1983)

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Figure A3.16 – Contour Plots (Serghides, 1984 - Eq. 2)

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Figure A3.17 – Contour Plots (Serghides, 1984 - Eq. 3)

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Figure A3.18 – Contour Plots (Tsal, 1989)

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Figure A3.19 – Contour Plots (Manadilli, 1997)

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Figure A3.20 – Contour Plots (Romeo et al., 2002)

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Figure A3.21 – Contour Plots (Sonnad and Goudar, 2006)

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Figure A3.22 – Contour Plots (Rao and Kumar, 2006)

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Figure A3.23 – Contour Plots (Buzzelli, 2008)

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Figure A3.24 – Contour Plots (Avci and Karagoz, 2009)

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Figure A3.25 – Contour Plots (Papaevangelou et al., 2010)

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Figure A3.26 – Contour Plots (Brkić, 2011 - Eq. A)

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Figure A3.27 – Contour Plots (Brkić, 2011 - Eq. B)

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Figure A3.28 – Contour Plots (Fang et al., 2011)

Appendix B – Improved Method of Estimating the Friction Factor

Appendix B1 – Tables

Equation	Absolute Error			Relative Percentage Error		
	Min	Max	Mean	Min	Max	Mean
(Eq. A1.23) (Buzzelli, 2008)	1.139E-12	9.401E-06	1.224E-06	3.547E-09	2.355E-02	0.005
(Eq. A1.16) (Serghides, 1984 - Eq. 2)	2.096E-12	9.467E-06	1.491E-06	4.309E-09	2.372E-02	0.006
(Eq. A1.14) (Zigrang and Sylvester, 1982 - Eq. 12)	2.096E-12	3.051E-05	4.027E-06	4.309E-09	1.305E-01	0.019
(Eq. A1.17) (Serghides, 1984 - Eq. 3)	2.095E-12	4.697E-05	6.668E-06	4.308E-09	3.680E-01	0.037
(Eq. A1.20) (Romeo et al., 2002)	2.566E-09	9.877E-05	2.528E-05	2.730E-05	1.226E-01	0.057
(Eq. A1.12) (Barr, 1981)	4.175E-11	2.588E-04	2.315E-05	3.180E-07	5.533E-01	0.063
(Eq. A1.9) (Chen, 1979)	3.493E-09	1.537E-04	3.388E-05	2.902E-05	3.387E-01	0.097
(Eq. A1.11) (Shacham, 1980)	1.738E-13	3.557E-04	2.941E-05	3.573E-10	8.912E-01	0.125
(Eq. 4.6) (Winning and Coole, 2015 – Eq 3)	3.347E-08	1.621E-04	3.577E-05	1.383E-04	4.378E-01	0.141
(Eq. A1.13) (Zigrang and Sylvester, 1982 - Eq. 11)	1.098E-12	1.866E-04	2.790E-05	2.258E-09	9.921E-01	0.141
(Eq. A1.28) (Fang et al., 2011)	5.795E-09	5.534E-04	5.412E-05	4.616E-05	5.347E-01	0.156
(Eq. A1.21) (Sonnad and Goudar, 2006)	1.285E-07	3.867E-04	5.222E-05	1.344E-03	9.688E-01	0.174
(Eq. A1.25) (Papaevangelou et al., 2010)	5.746E-09	1.491E-03	1.020E-04	3.273E-05	1.411E+00	0.230
(Eq. A1.15) (Haaland, 1983)	2.700E-08	9.734E-04	1.191E-04	1.675E-04	1.434E+00	0.373
(Eq. A1.19) (Manadilli, 1997)	6.875E-09	2.484E-03	1.561E-04	3.636E-05	2.710E+00	0.393
(Eq. A1.6) (Jain, 1976)	3.229E-09	2.533E-03	1.803E-04	1.642E-05	3.172E+00	0.452
(Eq. A1.8) (Churchill, 1977)	2.028E-09	1.723E-02	1.856E-04	1.089E-05	1.631E+01	0.475
(Eq. A1.7) (Swamee and Jain, 1976)	6.917E-08	2.786E-03	1.838E-04	1.769E-04	3.343E+00	0.478
(Eq. A1.27) (Brkić, 2011 - Eq. B)	1.058E-09	2.445E-03	1.850E-04	5.678E-06	2.799E+00	0.479
(Eq. A1.4) (Churchill, 1973)	1.142E-08	2.812E-03	1.891E-04	1.046E-04	3.407E+00	0.492
(Eq. A1.26) (Brkić, 2011 - Eq. A)	1.105E-09	1.723E-03	2.187E-04	1.364E-05	3.396E+00	0.721
(Eq. A1.5) (Eck, 1954)	6.901E-08	3.506E-03	3.899E-04	1.265E-04	8.209E+00	1.503
(Eq. A1.24) (Avci and Karagoz, 2009)	2.940E-08	6.184E-03	9.576E-04	1.398E-04	6.084E+00	1.716
(Eq. A1.3) (Wood, 1966)	2.265E-07	1.128E-02	1.536E-03	1.859E-03	2.825E+01	3.876
(Eq. A1.10) (Round, 1980)	1.573E-07	1.336E-02	2.260E-03	8.530E-04	1.315E+01	4.474
(Eq. A1.1) (Moody, 1947)	3.629E-08	2.809E-02	3.962E-03	2.869E-04	2.658E+01	6.098
(Eq. A1.18) (Tsal, 1989)	2.689E-09	4.132E-02	6.435E-03	1.693E-05	3.915E+01	8.894
(Eq. A1.2) Altshul 1952, cited in (Genić et al., 2011)	4.564E-08	4.132E-02	6.684E-03	2.187E-04	3.972E+01	11.449
(Eq. A1.22) (Rao and Kumar, 2006)	5.086E-06	3.412E-02	3.469E-03	2.838E-02	8.548E+01	13.270

Table B1.1 – Explicit Equations by Mean Relative Percentage Error

Application and Development of AEGIS for Pipeline Design

Equation	MSE	Magnitude of Error	Distribution
(Eq. A1.23) (Buzzelli, 2008)	5.622E-12	Very Small	Upper Diagonal
(Eq. A1.16) (Serghides, 1984 - Eq. 2)	7.511E-12	Very Small	Upper Diagonal
(Eq. A1.14) (Zigrang and Sylvester, 1982 - Eq. 12)	7.067E-11	Small	Upper Diagonal
(Eq. A1.17) (Serghides, 1984 - Eq. 3)	1.886E-10	Small	Upper Diagonal
(Eq. A1.20) (Romeo et al., 2002)	1.330E-09	Small	Diagonal Ridge
(Eq. A1.12) (Barr, 1981)	1.945E-09	Small	Upper Diagonal
(Eq. 4.6) (Winning and Coole, 2015 – Eq 3)	2.011E-09	Small	Diagonal Ridge Error
(Eq. A1.9) (Chen, 1979)	2.032E-09	Small	Diagonal Ridge Error
(Eq. A1.13) (Zigrang and Sylvester, 1982 - Eq. 11)	3.101E-09	Small	Upper Diagonal
(Eq. A1.11) (Shacham, 1980)	3.834E-09	Small	Upper Diagonal
(Eq. A1.28) (Fang et al., 2011)	6.551E-09	Small	Unclassified
(Eq. A1.21) (Sonnad and Goudar, 2006)	1.053E-08	Medium	Upper Diagonal
(Eq. A1.15) (Haaland, 1983)	2.670E-08	Medium	Upper Diagonal
(Eq. A1.25) (Papaevangelou et al., 2010)	4.089E-08	Medium	Unclassified
(Eq. A1.19) (Manadilli, 1997)	1.277E-07	Medium	Diagonal Ridge Error
(Eq. A1.6) (Jain, 1976)	1.325E-07	Medium	Upper Diagonal
(Eq. A1.27) (Brkić, 2011 - Eq. B)	1.352E-07	Medium	Upper Diagonal
(Eq. A1.26) (Brkić, 2011 - Eq. A)	1.511E-07	Medium	Upper Diagonal
(Eq. A1.7) (Swamee and Jain, 1976)	1.606E-07	Medium	Upper Diagonal
(Eq. A1.4) (Churchill, 1973)	1.677E-07	Medium	Upper Diagonal
(Eq. A1.8) (Churchill, 1977)	2.185E-07	Medium	Upper Diagonal
(Eq. A1.5) (Eck, 1954)	4.640E-07	Medium	Upper Diagonal
(Eq. A1.24) (Avci and Karagoz, 2009)	3.353E-06	Medium	Unclassified
(Eq. A1.3) (Wood, 1966)	5.913E-06	Large	Unclassified
(Eq. A1.10) (Round, 1980)	1.835E-05	Large	Unclassified
(Eq. A1.22) (Rao and Kumar, 2006)	5.159E-05	Large	Upper Diagonal
(Eq. A1.1) (Moody, 1947)	7.142E-05	Large	Unclassified
(Eq. A1.18) (Tsal, 1989)	1.746E-04	Large	Unclassified
(Eq. A1.2) Altshul 1952, cited in (Genić et al., 2011)	1.751E-04	Large	Unclassified

Table B1.2 – Explicit Equations by Mean Square Error

Application and Development of AEGIS for Pipeline Design

Equation		Relative Computational Efficiency				Rank
		Run 1	Run 2	Run 3	Mean	
(Eq. A1.2)	Altshul 1952, cited in (Genić et al., 2011)	0.4773	0.4766	0.4779	0.4773	1
(Eq. A1.1)	(Moody, 1947)	0.4926	0.4869	0.4881	0.4892	2
(Eq. A1.3)	(Wood, 1966)	0.5284	0.5226	0.5239	0.5250	3
(Eq. A1.5)	(Eck, 1954)	0.5539	0.5634	0.5597	0.5590	4
(Eq. A1.18)	(Tsal, 1989)	0.5692	0.5685	0.5648	0.5675	5
(Eq. A1.10)	(Round, 1980)	0.5795	0.5787	0.5802	0.5795	6
(Eq. A1.4)	(Churchill, 1973)	0.5846	0.5787	0.5853	0.5829	7
(Eq. A1.7)	(Swamee and Jain, 1976)	0.5948	0.5889	0.5955	0.5931	8
(Eq. A1.21)	(Sonnad and Goudar, 2006)	0.5999	0.5940	0.6058	0.5999	9
(Eq. A1.6)	(Jain, 1976)	0.6050	0.5991	0.6007	0.6016	10
(Eq. A1.8)	(Churchill, 1977)	0.5999	0.6042	0.6078	0.6040	11
(Eq. 4.6)	(Winning and Coole, 2015 – Eq 3)	0.6071	0.6114	0.6129	0.6105	12
(Eq. A1.24)	(Avci and Karagoz, 2009)	0.6173	0.6063	0.6129	0.6122	13
(Eq. A1.11)	(Shacham, 1980)	0.6224	0.6216	0.6232	0.6224	14
(Eq. A1.15)	(Haaland, 1983)	0.6377	0.6267	0.6334	0.6326	15
(Eq. A1.13)	(Zigrang and Sylvester, 1982 - Eq. 11)	0.6326	0.6369	0.6334	0.6343	16
(Eq. A1.28)	(Fang et al., 2011)	0.6429	0.6369	0.6437	0.6411	17
(Eq. A1.17)	(Serghides, 1984 - Eq. 3)	0.6480	0.6420	0.6488	0.6463	18
(Eq. A1.19)	(Manadilli, 1997)	0.6480	0.6471	0.6590	0.6514	19
(Eq. A1.9)	(Chen, 1979)	0.6531	0.6522	0.6539	0.6531	20
(Eq. A1.16)	(Serghides, 1984 - Eq. 2)	0.6633	0.6522	0.6590	0.6582	21
(Eq. A1.12)	(Barr, 1981)	0.6633	0.6573	0.6641	0.6616	22
(Eq. A1.27)	(Brkić, 2011 - Eq. B)	0.6735	0.6726	0.6743	0.6735	23
(Eq. A1.14)	(Zigrang and Sylvester, 1982 - Eq. 12)	0.6786	0.6675	0.6743	0.6735	24
(Eq. A1.22)	(Rao and Kumar, 2006)	0.6837	0.6828	0.6897	0.6854	25
(Eq. A1.23)	(Buzzelli, 2008)	0.6939	0.6879	0.6948	0.6922	26
(Eq. A1.26)	(Brkić, 2011 - Eq. A)	0.6939	0.6879	0.6999	0.6939	27
(Eq. A1.20)	(Romeo et al., 2002)	0.7144	0.7083	0.7102	0.7110	28
(Eq. A1.25)	(Papaevangelou et al., 2010)	0.7399	0.7390	0.7409	0.7399	29

Table B1.3 – Explicit Equations by Relative Computational Efficiency

Application and Development of AEGIS for Pipeline Design

Equation	Internal Iterations	Accuracy		Computational Efficiency		Combined Rank		
		MSE	Rank A1	Relative Effort	Rank B	A1 + B	Rank C1	
<i>(Eq. 4.6)</i>	<i>(Winning and Coole, 2015 – Eq 3)</i>	1	2.011E-09	7	0.6105	12	19	1
<i>(Eq. A1.21)</i>	<i>(Sonnad and Goudar, 2006)</i>	2	1.053E-08	12	0.5999	9	21	2
<i>(Eq. A1.17)</i>	<i>(Serghides, 1984 - Eq. 3)</i>	3	1.886E-10	4	0.6463	18	22	3
<i>(Eq. A1.16)</i>	<i>(Serghides, 1984 - Eq. 2)</i>	3	7.511E-12	2	0.6582	21	23	4
<i>(Eq. A1.13)</i>	<i>(Zigrang and Sylvester, 1982 - Eq. 11)</i>	2	3.101E-09	9	0.6343	16	25	5
<i>(Eq. A1.11)</i>	<i>(Shacham, 1980)</i>	2	3.834E-09	10	0.6224	14	24	6
<i>(Eq. A1.5)</i>	<i>(Eck, 1954)</i>	1	4.640E-07	22	0.5590	4	26	7
<i>(Eq. A1.23)</i>	<i>(Buzzelli, 2008)</i>	3	5.622E-12	1	0.6922	26	27	8
<i>(Eq. A1.14)</i>	<i>(Zigrang and Sylvester, 1982 - Eq. 12)</i>	3	7.067E-11	3	0.6735	24	27	9
<i>(Eq. A1.12)</i>	<i>(Barr, 1981)</i>	2	1.945E-09	6	0.6616	22	28	10
<i>(Eq. A1.6)</i>	<i>(Jain, 1976)</i>	1	1.325E-07	16	0.6016	10	26	11
<i>(Eq. A1.7)</i>	<i>(Swamee and Jain, 1976)</i>	1	1.606E-07	19	0.5931	8	27	12
<i>(Eq. A1.4)</i>	<i>(Churchill, 1973)</i>	1	1.677E-07	20	0.5829	7	27	13
<i>(Eq. A1.3)</i>	<i>(Wood, 1966)</i>	0	5.913E-06	24	0.5250	3	27	14
<i>(Eq. A1.9)</i>	<i>(Chen, 1979)</i>	2	2.032E-09	8	0.6531	20	28	15
<i>(Eq. A1.28)</i>	<i>(Fang et al., 2011)</i>	1	6.551E-09	11	0.6411	17	28	16
<i>(Eq. A1.15)</i>	<i>(Haaland, 1983)</i>	1	2.670E-08	13	0.6326	15	28	17
<i>(Eq. A1.1)</i>	<i>(Moody, 1947)</i>	0	7.142E-05	27	0.4892	2	29	18
<i>(Eq. A1.8)</i>	<i>(Churchill, 1977)</i>	1	2.185E-07	21	0.6040	11	32	19
<i>(Eq. A1.2)</i>	<i>Altshul 1952, cited in (Genić et al., 2011)</i>	0	1.751E-04	29	0.4773	1	30	20
<i>(Eq. A1.10)</i>	<i>(Round, 1980)</i>	1	1.835E-05	25	0.5795	6	31	21
<i>(Eq. A1.20)</i>	<i>(Romeo et al., 2002)</i>	3	1.330E-09	5	0.7110	28	33	22
<i>(Eq. A1.19)</i>	<i>(Manadilli, 1997)</i>	1	1.277E-07	15	0.6514	19	34	23
<i>(Eq. A1.18)</i>	<i>(Tsal, 1989)</i>	0	1.746E-04	28	0.5675	5	33	24
<i>(Eq. A1.24)</i>	<i>(Avci and Karagoz, 2009)</i>	2	3.353E-06	23	0.6122	13	36	25
<i>(Eq. A1.27)</i>	<i>(Brkić, 2011 - Eq. B)</i>	4	1.352E-07	17	0.6735	23	40	26
<i>(Eq. A1.25)</i>	<i>(Papaevangelou et al., 2010)</i>	2	4.089E-08	14	0.7399	29	43	27
<i>(Eq. A1.26)</i>	<i>(Brkić, 2011 - Eq. A)</i>	4	1.511E-07	18	0.6939	27	45	28
<i>(Eq. A1.22)</i>	<i>(Rao and Kumar, 2006)</i>	2	5.159E-05	26	0.6854	25	51	29

Table B1.4 – Explicit Equations by MSE and Computational Efficiency

Application and Development of AEGIS for Pipeline Design

Equation	Internal Iterations	Accuracy		Computational Efficiency		Combined Rank		
		MRPE	Rank A2	Relative Effort	Rank B	A2 + B	Rank C2	
<i>(Eq. 4.6)</i>	(Winning and Coole, 2015 – Eq 3)	1	0.141	9	0.6105	12	21	1
<i>(Eq. A1.21)</i>	(Sonnad and Goudar, 2006)	2	0.174	12	0.5999	9	21	2
<i>(Eq. A1.17)</i>	(Serghides, 1984 - Eq. 3)	3	0.037	4	0.6463	18	22	3
<i>(Eq. A1.11)</i>	(Shacham, 1980)	2	0.125	8	0.6224	14	22	4
<i>(Eq. A1.16)</i>	(Serghides, 1984 - Eq. 2)	3	0.006	2	0.6582	21	23	5
<i>(Eq. A1.13)</i>	(Zigrang and Sylvester, 1982 - Eq. 11)	2	0.141	10	0.6343	16	26	6
<i>(Eq. A1.6)</i>	(Jain, 1976)	1	0.452	16	0.6016	10	26	7
<i>(Eq. A1.7)</i>	(Swamee and Jain, 1976)	1	0.478	18	0.5931	8	26	8
<i>(Eq. A1.5)</i>	(Eck, 1954)	1	1.503	22	0.5590	4	26	9
<i>(Eq. A1.23)</i>	(Buzzelli, 2008)	3	0.005	1	0.6922	26	27	10
<i>(Eq. A1.14)</i>	(Zigrang and Sylvester, 1982 - Eq. 12)	3	0.019	3	0.6735	24	27	11
<i>(Eq. A1.9)</i>	(Chen, 1979)	2	0.097	7	0.6531	20	27	12
<i>(Eq. A1.4)</i>	(Churchill, 1973)	1	0.492	20	0.5829	7	27	13
<i>(Eq. A1.3)</i>	(Wood, 1966)	0	3.876	24	0.5250	3	27	14
<i>(Eq. A1.12)</i>	(Barr, 1981)	2	0.063	6	0.6616	22	28	15
<i>(Eq. A1.28)</i>	(Fang et al., 2011)	1	0.156	11	0.6411	17	28	16
<i>(Eq. A1.8)</i>	(Churchill, 1977)	1	0.475	17	0.6040	11	28	17
<i>(Eq. A1.1)</i>	(Moody, 1947)	0	6.098	26	0.4892	2	28	18
<i>(Eq. A1.15)</i>	(Haaland, 1983)	1	0.373	14	0.6326	15	29	19
<i>(Eq. A1.2)</i>	Altshul 1952, cited in (Genić et al., 2011)	0	11.449	28	0.4773	1	29	20
<i>(Eq. A1.10)</i>	(Round, 1980)	1	4.474	25	0.5795	6	31	21
<i>(Eq. A1.18)</i>	(Tsal, 1989)	0	8.894	27	0.5675	5	32	22
<i>(Eq. A1.20)</i>	(Romeo et al., 2002)	3	0.057	5	0.7110	28	33	23
<i>(Eq. A1.19)</i>	(Manadilli, 1997)	1	0.393	15	0.6514	19	34	24
<i>(Eq. A1.24)</i>	(Avci and Karagoz, 2009)	2	1.716	23	0.6122	13	36	25
<i>(Eq. A1.25)</i>	(Papaevangelou et al., 2010)	2	0.230	13	0.7399	29	42	26
<i>(Eq. A1.27)</i>	(Brkić, 2011 - Eq. B)	4	0.479	19	0.6735	23	42	27
<i>(Eq. A1.26)</i>	(Brkić, 2011 - Eq. A)	4	0.721	21	0.6939	27	48	28
<i>(Eq. A1.22)</i>	(Rao and Kumar, 2006)	2	13.270	29	0.6854	25	54	29

Table B1.5 – Explicit Equations by MRPE and Computational Efficiency

Appendix C – Determination of Location Class

Appendix C1 – Extract from ASME B31.8-2012

840.2 Buildings Intended for Human Occupancy

840.2.1 General

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Appendix D – Soil Erosion Classification using Remote Sensed Data

Appendix D1 – WMO Data for Yevlax (Azerbaijan)

Available at: <http://data.un.org/Explorer.aspx?d=CLINO>

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Element 16: Wind Speed (m/sec)

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Element BT: Number Days with Occurrence of Rain (count)

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Appendix D2 – Vegetation Classification

256 Colour	Category	256 Colour	Category	256 Colour	Category	256 Colour	Category
0	Water/Ice	40	Rock	80	Soil	120	Soil
1	Water/Ice	41	Rock	81	Soil	121	Soil
2	Water/Ice	42	Vegetation	82	Soil	122	Soil/Rock
3	Water/Ice	43	Vegetation	83	Soil	123	Soil/Rock
4	Water/Ice	44	Vegetation	84	Soil/Rock	124	Soil/Rock
5	Water/Ice	45	Vegetation	85	Soil/Rock	125	Soil/Rock
6	Vegetation	46	Vegetation	86	Soil/Rock	126	Vegetation
7	Water/Ice	47	Vegetation	87	Soil/Rock	127	Vegetation
8	Cloud	48	Vegetation	88	Soil/Rock	128	Vegetation
9	Cloud	49	Vegetation	89	Soil/Rock	129	Cloud
10	Cloud	50	Water/Ice	90	Vegetation	130	Cloud
11	Cloud	51	Water/Ice	91	Vegetation	131	Cloud
12	Vegetation	52	Water/Ice	92	Vegetation	132	Vegetation
13	Vegetation	53	Water/Ice	93	Vegetation	133	Vegetation
14	Water/Ice	54	Vegetation	94	Vegetation	134	Vegetation
15	Vegetation	55	Vegetation	95	Vegetation	135	Vegetation
16	Vegetation	56	Vegetation	96	Vegetation	136	Vegetation
17	Vegetation	57	Water/Ice	97	Vegetation	137	Vegetation
18	Vegetation	58	Water/Ice	98	Vegetation	138	Vegetation
19	Vegetation	59	Water/Ice	99	Vegetation	139	Vegetation
20	Vegetation	60	Vegetation	100	Water/Ice	140	Vegetation
21	Water/Ice	61	Vegetation	101	Water/Ice	141	Vegetation
22	Water/Ice	62	Vegetation	102	Water/Ice	142	Vegetation
23	Water/Ice	63	Vegetation	103	Water/Ice	143	Vegetation
24	Vegetation	64	Cloud	104	Water/Ice	144	Soil
25	Vegetation	65	Cloud	105	Water/Ice	145	Soil
26	Vegetation	66	Vegetation	106	Water/Ice	146	Soil
27	Vegetation	67	Vegetation	107	Water/Ice	147	Soil
28	Water/Ice	68	Vegetation	108	Soil/Rock	148	Soil
29	Water/Ice	69	Vegetation	109	Soil/Rock	149	Soil
30	Vegetation	70	Cloud	110	Soil/Rock	150	Soil
31	Vegetation	71	Cloud	111	Soil/Rock	151	Soil
32	Vegetation	72	Soil	112	Soil/Rock	152	Soil
33	Vegetation	73	Soil	113	Soil/Rock	153	Soil
34	Rock	74	Soil	114	Soil/Rock	154	Soil
35	Rock	75	Soil	115	Soil/Rock	155	Soil
36	Rock	76	Soil	116	Soil/Rock	156	Soil
37	Rock	77	Soil	117	Soil/Rock	157	Soil
38	Rock	78	Soil	118	Soil/Rock	158	Soil
39	Rock	79	Soil	119	Soil/Rock	159	Soil

Application and Development of AEGIS for Pipeline Design

256 Colour	Category	256 Colour	Category	256 Colour	Category	256 Colour	Category
160	Soil	191	Soil	222	Soil		
161	Soil	192	Soil	223	Soil		
162	Soil	193	Soil	224	Soil		
163	Soil	194	Soil	225	Soil		
164	Soil	195	Soil	226	Soil		
165	Soil	196	Soil	227	Soil		
166	Soil	197	Soil	228	Soil		
167	Soil	198	Soil	229	Soil		
168	Vegetation	199	Soil	230	Soil		
169	Vegetation	200	Soil	231	Soil		
170	Vegetation	201	Cloud	232	Soil		
171	Vegetation	202	Cloud	233	Soil		
172	Cloud	203	Cloud	234	Soil		
173	Cloud	204	Vegetation	235	Soil		
174	Vegetation	205	Vegetation	236	Soil		
175	Vegetation	206	Vegetation	237	Soil		
176	Vegetation	207	Cloud	238	Soil		
177	Vegetation	208	Cloud	239	Soil		
178	Vegetation	209	Cloud	240	Cloud		
179	Vegetation	210	Vegetation	241	Cloud		
180	Soil	211	Vegetation	242	Cloud		
181	Soil	212	Vegetation	243	Cloud		
182	Soil	213	Vegetation	244	Cloud		
183	Soil	214	Cloud	245	Cloud		
184	Soil	215	Cloud	246	Cloud		
185	Soil	216	Soil	247	Cloud		
186	Soil	217	Soil	248	Cloud		
187	Soil	218	Soil	249	Cloud		
188	Soil	219	Soil	250	Cloud		
189	Soil	220	Soil	251	Cloud		
190	Soil	221	Soil				

Appendix D3 – Azerbaijan Aggregated Values by 1,000m Sections

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
0	1	2.00	2	2.00	2	0
1	2	1.92	2	2.00	2	0
2	3	2.00	2	2.00	2	0
3	4	1.73	2	2.00	2	0
4	5	2.00	2	2.00	2	0
5	6	2.00	2	2.71	3	-1
6	7	2.36	3	5.57	6	-3
7	8	2.00	2	3.64	4	-2
8	9	2.00	2	3.80	4	-2
9	10	2.00	2	3.43	3	-1
10	11	2.00	2	3.00	3	-1
11	12	2.00	2	4.07	4	-2
12	13	2.15	3	4.92	5	-2
13	14	2.00	2	1.00	1	1
14	15	2.00	2	1.00	1	1
15	16	2.00	2	1.00	1	1
16	17	2.00	2	1.00	1	1
17	18	2.00	2	1.00	1	1
18	19	2.00	2	1.00	1	1
19	20	2.00	2	1.00	1	1
20	21	2.00	2	1.00	1	1
21	22	2.00	2	1.00	1	1
22	23	2.00	2	1.00	1	1
23	24	2.00	2	2.21	2	0
24	25	2.38	3	6.00	6	-3
25	26	2.85	3	6.00	6	-3
26	27	2.53	3	6.00	6	-3
27	28	2.80	3	5.00	5	-2
28	29	2.00	2	3.00	3	-1
29	30	2.00	2	2.08	2	0
30	31	2.00	2	2.00	2	0
31	32	2.00	2	2.00	2	0
32	33	2.00	2	2.00	2	0
33	34	2.00	2	2.00	2	0
34	35	2.00	2	2.00	2	0
35	36	2.00	2	2.00	2	0
36	37	2.00	2	2.00	2	0
37	38	2.00	2	2.00	2	0

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
38	39	2.00	2	2.00	2	0
39	40	2.00	2	2.00	2	0
40	41	2.00	2	2.00	2	0
41	42	2.00	2	2.00	2	0
42	43	2.00	2	2.00	2	0
43	44	2.00	2	2.00	2	0
44	45	2.00	2	2.00	2	0
45	46	2.00	2	2.00	2	0
46	47	2.00	2	2.00	2	0
47	48	2.00	2	2.93	3	-1
48	49	2.00	2	3.00	3	-1
49	50	2.00	2	3.00	3	-1
50	51	2.27	3	3.53	4	-1
51	52	2.00	2	2.00	2	0
52	53	2.00	2	2.00	2	0
53	54	2.00	2	2.00	2	0
54	55	2.00	2	2.00	2	0
55	56	1.93	2	2.00	2	0
56	57	1.92	2	2.00	2	0
57	58	2.50	3	2.00	2	1
58	59	2.00	2	2.00	2	0
59	60	2.00	2	2.00	2	0
60	61	2.00	2	2.00	2	0
61	62	2.00	2	2.00	2	0
62	63	2.00	2	2.00	2	0
63	64	2.00	2	2.00	2	0
64	65	2.00	2	2.00	2	0
65	66	2.00	2	2.00	2	0
66	67	2.00	2	2.00	2	0
67	68	2.00	2	2.00	2	0
68	69	2.00	2	2.00	2	0
69	70	2.00	2	2.00	2	0
70	71	2.00	2	2.00	2	0
71	72	2.00	2	2.00	2	0
72	73	2.00	2	2.00	2	0
73	74	2.00	2	2.00	2	0
74	75	2.00	2	2.00	2	0
75	76	2.00	2	2.00	2	0
76	77	2.00	2	2.00	2	0

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
77	78	2.00	2	2.00	2	0
78	79	2.00	2	2.00	2	0
79	80	2.00	2	2.00	2	0
80	81	2.00	2	2.00	2	0
81	82	2.00	2	2.00	2	0
82	83	2.00	2	2.00	2	0
83	84	2.00	2	2.00	2	0
84	85	2.00	2	2.00	2	0
85	86	2.00	2	2.00	2	0
86	87	2.00	2	2.00	2	0
87	88	2.00	2	2.00	2	0
88	89	2.00	2	2.00	2	0
89	90	2.00	2	2.00	2	0
90	91	2.00	2	2.00	2	0
91	92	2.00	2	2.00	2	0
92	93	2.00	2	2.00	2	0
93	94	2.00	2	2.00	2	0
94	95	2.00	2	2.00	2	0
95	96	2.00	2	2.00	2	0
96	97	2.00	2	2.00	2	0
97	98	2.00	2	2.00	2	0
98	99	2.00	2	2.00	2	0
99	100	2.00	2	2.00	2	0
100	101	2.00	2	2.00	2	0
101	102	2.00	2	2.00	2	0
102	103	2.00	2	2.00	2	0
103	104	2.00	2	2.00	2	0
104	105	2.00	2	2.00	2	0
105	106	2.00	2	2.00	2	0
106	107	2.00	2	2.00	2	0
107	108	2.00	2	2.00	2	0
108	109	2.00	2	2.00	2	0
109	110	2.00	2	2.00	2	0
110	111	2.00	2	2.00	2	0
111	112	2.00	2	2.00	2	0
112	113	2.00	2	2.00	2	0
113	114	2.00	2	2.00	2	0
114	115	2.00	2	2.00	2	0
115	116	2.00	2	2.00	2	0

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance	
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average		
116	117	2.00	2	2.00	2	0	
117	118	2.00	2	2.00	2	0	
118	119	2.00	2	2.00	2	0	
119	120	2.00	2	2.00	2	0	
120	121	2.00	2	2.00	2	0	
121	122	1.81	2	2.00	2	0	
122	123	1.93	2	2.00	2	0	
123	124	2.00	2	2.00	2	0	
124	125	2.00	2	2.00	2	0	
125	126	1.89	2	2.00	2	0	
126	127	No Data (SRTM Void)					
127	128	2.67	3	2.00	2	1	
128	129	2.50	3	2.00	2	1	
129	130	1.86	2	2.00	2	0	
130	131	2.00	2	2.00	2	0	
131	132	2.10	3	2.00	2	1	
132	133	2.00	2	2.00	2	0	
133	134	2.00	2	2.00	2	0	
134	135	2.00	2	2.00	2	0	
135	136	2.00	2	2.00	2	0	
136	137	2.00	2	2.00	2	0	
137	138	2.00	2	2.00	2	0	
138	139	2.00	2	2.00	2	0	
139	140	2.00	2	2.00	2	0	
140	141	2.00	2	2.00	2	0	
141	142	2.00	2	2.00	2	0	
142	143	2.00	2	2.00	2	0	
143	144	2.00	2	2.00	2	0	
144	145	2.00	2	2.00	2	0	
145	146	2.00	2	2.00	2	0	
146	147	2.00	2	2.00	2	0	
147	148	2.00	2	2.00	2	0	
148	149	2.00	2	2.00	2	0	
149	150	2.00	2	2.00	2	0	
150	151	2.00	2	2.00	2	0	
151	152	2.00	2	2.00	2	0	
152	153	2.00	2	2.00	2	0	
153	154	2.00	2	2.00	2	0	
154	155	2.00	2	2.00	2	0	

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
155	156	2.00	2	2.00	2	0
156	157	2.00	2	2.00	2	0
157	158	2.00	2	2.00	2	0
158	159	2.00	2	2.00	2	0
159	160	2.00	2	2.00	2	0
160	161	1.85	2	2.00	2	0
161	162	2.50	3	2.00	2	1
162	163	1.69	2	2.00	2	0
163	164	1.75	2	2.00	2	0
164	165	2.07	3	2.00	2	1
165	166	2.00	2	2.00	2	0
166	167	2.00	2	2.00	2	0
167	168	2.00	2	2.00	2	0
168	169	2.00	2	2.00	2	0
169	170	2.00	2	2.00	2	0
170	171	2.00	2	2.00	2	0
171	172	2.00	2	2.00	2	0
172	173	2.00	2	2.00	2	0
173	174	1.93	2	2.00	2	0
174	175	2.00	2	2.00	2	0
175	176	2.00	2	2.00	2	0
176	177	2.00	2	2.00	2	0
177	178	2.00	2	2.00	2	0
178	179	2.00	2	2.00	2	0
179	180	2.00	2	2.00	2	0
180	181	1.94	2	2.00	2	0
181	182	2.00	2	2.00	2	0
182	183	2.00	2	2.00	2	0
183	184	2.00	2	2.00	2	0
184	185	2.00	2	2.00	2	0
185	186	2.00	2	2.00	2	0
186	187	2.00	2	2.00	2	0
187	188	2.00	2	2.00	2	0
188	189	2.00	2	2.00	2	0
189	190	2.00	2	2.00	2	0
190	191	2.00	2	2.00	2	0
191	192	2.00	2	2.00	2	0
192	193	2.00	2	2.00	2	0
193	194	2.00	2	2.00	2	0

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
194	195	2.00	2	2.00	2	0
195	196	2.00	2	2.00	2	0
196	197	2.00	2	2.00	2	0
197	198	2.00	2	2.00	2	0
198	199	2.00	2	2.00	2	0
199	200	2.00	2	2.00	2	0
200	201	2.00	2	2.00	2	0
201	202	2.00	2	2.00	2	0
202	203	2.00	2	2.00	2	0
203	204	2.00	2	2.00	2	0
204	205	2.00	2	2.00	2	0
205	206	2.00	2	2.00	2	0
206	207	2.00	2	2.00	2	0
207	208	2.00	2	2.00	2	0
208	209	2.00	2	2.00	2	0
209	210	2.00	2	2.00	2	0
210	211	2.00	2	2.00	2	0
211	212	2.00	2	2.00	2	0
212	213	1.67	2	2.00	2	0
213	214	2.00	2	2.00	2	0
214	215	2.00	2	2.00	2	0
215	216	2.00	2	2.00	2	0
216	217	2.00	2	2.00	2	0
217	218	2.00	2	2.00	2	0
218	219	2.00	2	2.00	2	0
219	220	2.00	2	2.00	2	0
220	221	2.00	2	2.00	2	0
221	222	2.00	2	2.00	2	0
222	223	2.00	2	2.00	2	0
223	224	2.00	2	2.00	2	0
224	225	2.00	2	2.00	2	0
225	226	2.00	2	2.00	2	0
226	227	2.00	2	2.00	2	0
227	228	2.00	2	2.00	2	0
228	229	2.00	2	2.00	2	0
229	230	2.00	2	2.00	2	0
230	231	2.00	2	2.00	2	0
231	232	2.00	2	2.00	2	0
232	233	2.00	2	2.00	2	0

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
233	234	2.00	2	2.00	2	0
234	235	2.00	2	2.00	2	0
235	236	2.00	2	2.00	2	0
236	237	2.00	2	2.00	2	0
237	238	2.00	2	2.00	2	0
238	239	2.00	2	2.00	2	0
239	240	2.00	2	2.00	2	0
240	241	2.00	2	2.00	2	0
241	242	2.00	2	2.00	2	0
242	243	2.00	2	2.00	2	0
243	244	2.00	2	2.20	2	0
244	245	2.00	2	3.00	3	-1
245	246	2.00	2	3.00	3	-1
246	247	2.00	2	3.00	3	-1
247	248	2.00	2	3.00	3	-1
248	249	2.00	2	2.29	2	0
249	250	2.00	2	2.00	2	0
250	251	2.00	2	2.00	2	0
251	252	2.00	2	2.00	2	0
252	253	2.00	2	2.00	2	0
253	254	2.00	2	2.00	2	0
254	255	2.00	2	2.00	2	0
255	256	2.00	2	2.00	2	0
256	257	2.00	2	2.00	2	0
257	258	2.00	2	2.00	2	0
258	259	2.00	2	2.00	2	0
259	260	2.00	2	2.00	2	0
260	261	2.00	2	2.00	2	0
261	262	2.00	2	2.00	2	0
262	263	2.00	2	2.00	2	0
263	264	2.00	2	2.00	2	0
264	265	2.00	2	2.00	2	0
265	266	2.00	2	2.00	2	0
266	267	2.00	2	2.00	2	0
267	268	2.00	2	2.00	2	0
268	269	1.93	2	2.00	2	0
269	270	2.00	2	2.00	2	0
270	271	2.00	2	2.00	2	0
271	272	2.00	2	2.00	2	0

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
272	273	2.00	2	2.00	2	0
273	274	2.00	2	2.00	2	0
274	275	2.00	2	2.00	2	0
275	276	2.00	2	2.00	2	0
276	277	2.00	2	2.00	2	0
277	278	2.00	2	2.00	2	0
278	279	2.00	2	2.00	2	0
279	280	2.00	2	2.00	2	0
280	281	2.00	2	2.00	2	0
281	282	2.00	2	2.00	2	0
282	283	2.00	2	2.00	2	0
283	284	2.00	2	2.00	2	0
284	285	2.00	2	2.00	2	0
285	286	2.00	2	2.00	2	0
286	287	2.00	2	2.00	2	0
287	288	2.00	2	2.00	2	0
288	289	2.00	2	2.00	2	0
289	290	2.00	2	2.00	2	0
290	291	2.00	2	2.00	2	0
291	292	2.00	2	2.00	2	0
292	293	2.00	2	2.00	2	0
293	294	2.00	2	2.00	2	0
294	295	2.00	2	2.00	2	0
295	296	2.00	2	2.00	2	0
296	297	2.00	2	2.00	2	0
297	298	2.00	2	2.00	2	0
298	299	2.00	2	2.00	2	0
299	300	2.00	2	2.00	2	0
300	301	1.92	2	2.00	2	0
301	302	2.00	2	2.00	2	0
302	303	1.93	2	2.00	2	0
303	304	2.00	2	2.23	2	0
304	305	2.00	2	3.00	3	-1
305	306	2.00	2	3.00	3	-1
306	307	2.00	2	3.00	3	-1
307	308	2.00	2	3.00	3	-1
308	309	2.00	2	3.00	3	-1
309	310	2.00	2	4.73	5	-3
310	311	2.00	2	5.00	5	-3

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
311	312	2.00	2	3.92	4	-2
312	313	2.00	2	3.00	3	-1
313	314	2.00	2	3.00	3	-1
314	315	2.00	2	2.86	3	-1
315	316	2.14	3	2.00	2	1
316	317	2.00	2	2.00	2	0
317	318	2.00	2	2.00	2	0
318	319	2.00	2	2.00	2	0
319	320	2.08	3	2.75	3	0
320	321	2.00	2	2.50	3	-1
321	322	2.00	2	2.00	2	0
322	323	2.00	2	2.00	2	0
323	324	2.00	2	2.00	2	0
324	325	2.00	2	2.00	2	0
325	326	2.00	2	2.00	2	0
326	327	2.00	2	2.00	2	0
327	328	2.00	2	2.00	2	0
328	329	2.00	2	2.00	2	0
329	330	2.00	2	2.00	2	0
330	331	2.00	2	2.00	2	0
331	332	2.00	2	2.00	2	0
332	333	2.00	2	2.00	2	0
333	334	2.00	2	2.00	2	0
334	335	2.00	2	2.00	2	0
335	336	2.00	2	2.00	2	0
336	337	2.00	2	2.00	2	0
337	338	2.00	2	2.00	2	0
338	339	2.00	2	2.00	2	0
339	340	2.00	2	2.00	2	0
340	341	2.00	2	2.00	2	0
341	342	2.00	2	2.00	2	0
342	343	2.00	2	2.00	2	0
343	344	2.00	2	2.21	2	0
344	345	2.00	2	3.00	3	-1
345	346	2.00	2	3.00	3	-1
346	347	2.00	2	3.00	3	-1
347	348	2.00	2	3.00	3	-1
348	349	2.00	2	3.00	3	-1
349	350	2.00	2	3.00	3	-1

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
350	351	2.00	2	3.00	3	-1
351	352	2.00	2	3.36	3	-1
352	353	2.00	2	3.50	4	-2
353	354	2.00	2	3.79	4	-2
354	355	2.00	2	3.15	3	-1
355	356	2.07	3	3.29	3	0
356	357	2.00	2	3.00	3	-1
357	358	2.00	2	3.00	3	-1
358	359	2.00	2	3.00	3	-1
359	360	2.00	2	3.00	3	-1
360	361	2.00	2	3.00	3	-1
361	362	2.00	2	3.00	3	-1
362	363	2.00	2	3.00	3	-1
363	364	2.07	3	3.00	3	0
364	365	2.00	2	3.00	3	-1
365	366	2.00	2	3.00	3	-1
366	367	2.00	2	3.00	3	-1
367	368	2.14	3	3.00	3	0
368	369	2.00	2	3.00	3	-1
369	370	2.00	2	3.00	3	-1
370	371	2.00	2	3.00	3	-1
371	372	2.00	2	3.00	3	-1
372	373	2.00	2	3.00	3	-1
373	374	2.00	2	3.00	3	-1
374	375	2.94	3	3.00	3	0
375	376	3.31	4	3.00	3	1
376	377	2.40	3	3.00	3	0
377	378	2.00	2	3.00	3	-1
378	379	2.00	2	3.00	3	-1
379	380	2.00	2	3.00	3	-1
380	381	2.00	2	3.00	3	-1
381	382	2.00	2	3.00	3	-1
382	383	2.00	2	3.00	3	-1
383	384	2.00	2	3.00	3	-1
384	385	2.00	2	3.00	3	-1
385	386	2.00	2	3.00	3	-1
386	387	2.00	2	3.00	3	-1
387	388	2.62	3	3.00	3	0
388	389	2.23	3	3.62	4	-1

Application and Development of AEGIS for Pipeline Design

KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
389	390	2.00	2	3.00	3	-1
390	391	2.08	3	3.00	3	0
391	392	2.15	3	3.38	3	0
392	393	2.00	2	4.00	4	-2
393	394	2.07	3	3.57	4	-1
394	395	2.50	3	3.00	3	0
395	396	2.64	3	5.14	5	-2
396	397	2.93	3	6.00	6	-3
397	398	2.15	3	6.00	6	-3
398	399	2.00	2	3.00	3	-1
399	400	2.00	2	3.00	3	-1
400	401	2.42	3	3.00	3	0
401	402	2.67	3	3.00	3	0
402	403	2.58	3	3.00	3	0
403	404	2.42	3	3.00	3	0
404	405	2.33	3	2.92	3	0
405	406	2.00	2	2.00	2	0
406	407	2.00	2	2.00	2	0
407	408	2.00	2	2.00	2	0
408	409	2.00	2	2.00	2	0
409	410	2.00	2	2.00	2	0
410	411	2.08	3	2.67	3	0
411	412	2.00	2	3.25	3	-1
412	413	2.38	3	3.00	3	0
413	414	2.14	3	3.00	3	0
414	415	2.00	2	3.00	3	-1
415	416	2.00	2	3.00	3	-1
416	417	2.07	3	3.00	3	0
417	418	2.08	3	3.00	3	0
418	419	2.07	3	3.00	3	0
419	420	2.00	2	3.00	3	-1
420	421	2.00	2	3.00	3	-1
421	422	2.00	2	3.00	3	-1
422	423	2.00	2	3.00	3	-1
423	424	2.00	2	3.00	3	-1
424	425	2.00	2	3.00	3	-1
425	426	2.00	2	3.00	3	-1
426	427	2.00	2	3.00	3	-1
427	428	2.00	2	3.00	3	-1

Application and Development of AEGIS for Pipeline Design

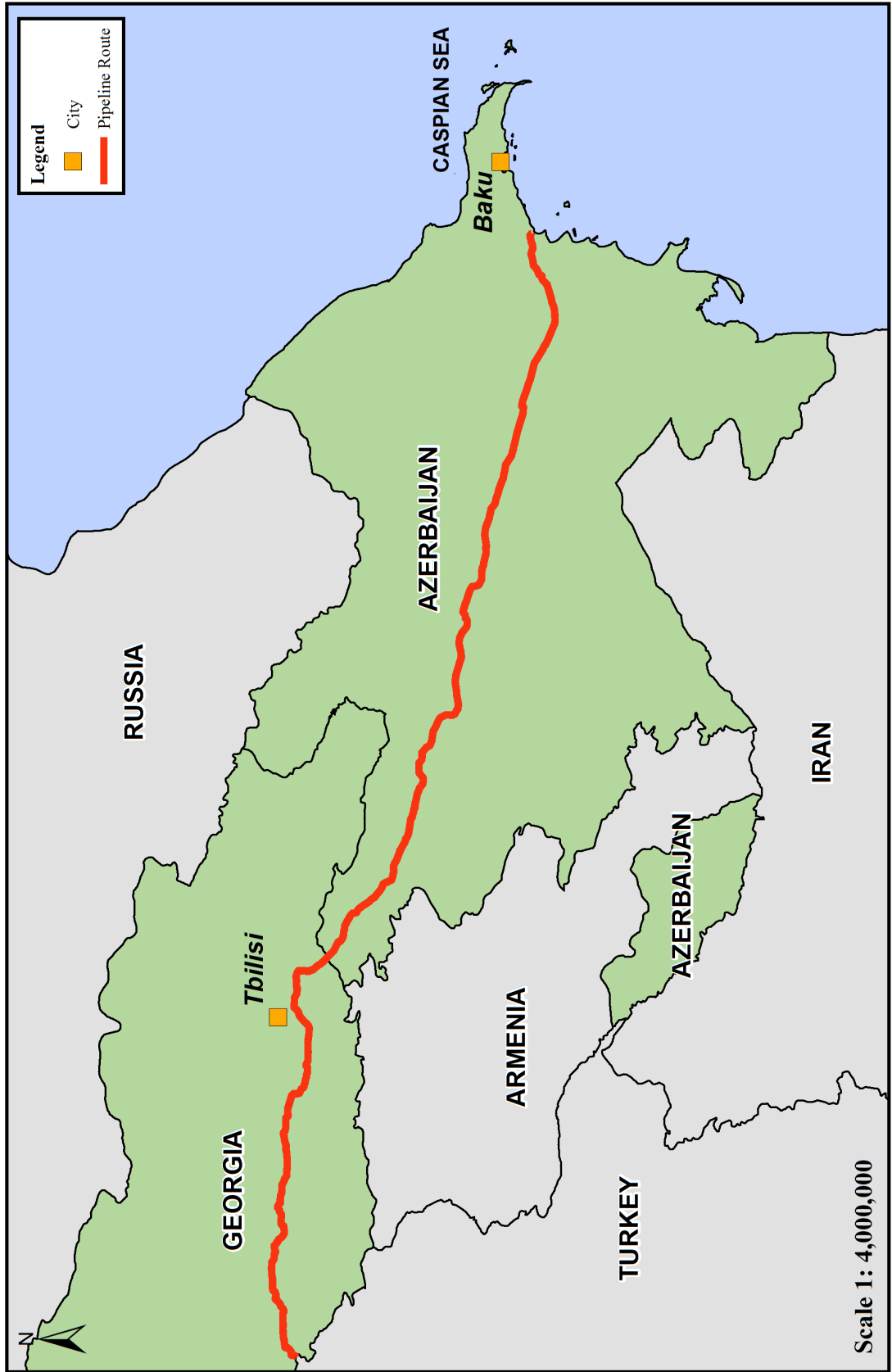
KP		Erosion Class (Calculated)		Erosion Class (Base Case)		Variance
From	To	Aggregated Value	Rounded Average	Aggregated Value	Rounded Average	
428	429	1.80	2	3.00	3	-1
429	430	2.00	2	3.00	3	-1
430	431	2.15	3	3.00	3	0
431	432	2.00	2	3.00	3	-1
432	433	2.00	2	3.00	3	-1
433	434	2.00	2	3.00	3	-1
434	435	2.00	2	3.00	3	-1
435	436	2.00	2	3.00	3	-1
436	437	2.00	2	3.00	3	-1
437	438	2.00	2	3.00	3	-1
438	439	2.00	2	3.00	3	-1
439	440	2.00	2	3.00	3	-1
440	441	2.00	2	3.00	3	-1
441	442	2.00	2	3.00	3	-1

Appendix D4 – Azerbaijan Aggregated Values by 500m and 250m

Variance between Calculated and Field Values	Number	Percentage
-5	0	0.0%
-4	2	0.2%
-3	16	1.8%
-2	16	1.8%
-1	188	21.4%
0	624	70.9%
1	34	3.9%
2	0	0.0%
3	0	0.0%
4	0	0.0%
5	0	0.0%
Percentage of Calculated Values ± 1 from the Field Values		96.1%
Points with Data:	880	99.5%
Points with no Data:	4	0.5%
Total Points:	884	

Variance between Calculated and Field Values	Number	Percentage
-5	0	0.0%
-4	10	0.6%
-3	27	1.5%
-2	31	1.8%
-1	394	22.5%
0	1228	70.2%
1	59	3.4%
2	0	0.0%
3	0	0.0%
4	0	0.0%
5	0	0.0%
Percentage of Calculated Values ± 1 from the Field Values		96.1%
Points with Data:	1749	99.0%
Points with no Data:	18	1.0%
Total Points:	1767	

Appendix D5 – GIS Maps



Map 1 – Study Area Overview

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Map 2 – Study Area Landsat Imagery

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Map 3 – WMO Weather Station Locations

This item has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

Map 4 – Vegetation Classification

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This item has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

Map 5 – Soil Classification

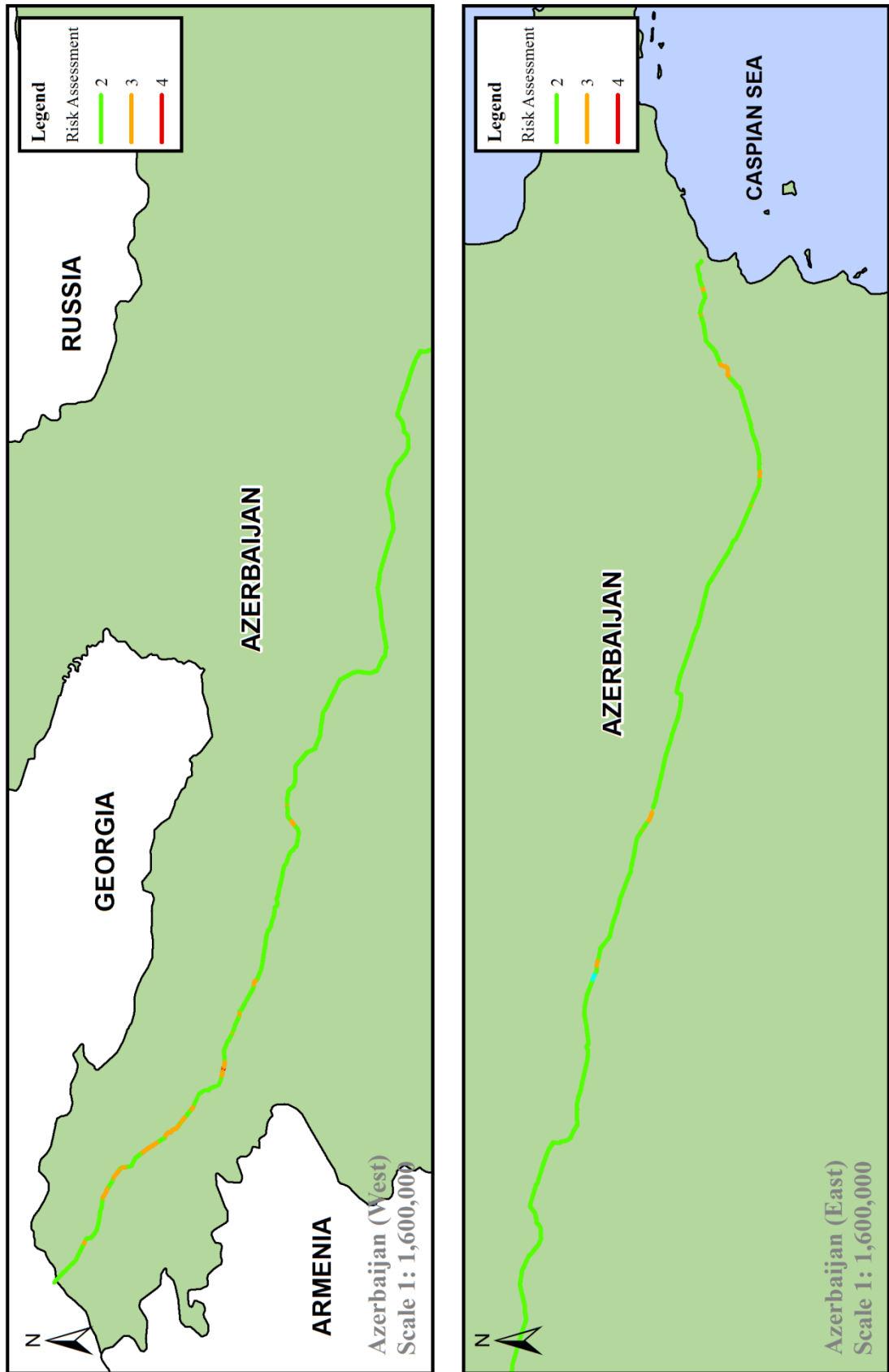
Application and Development of AEGIS for Pipeline Design

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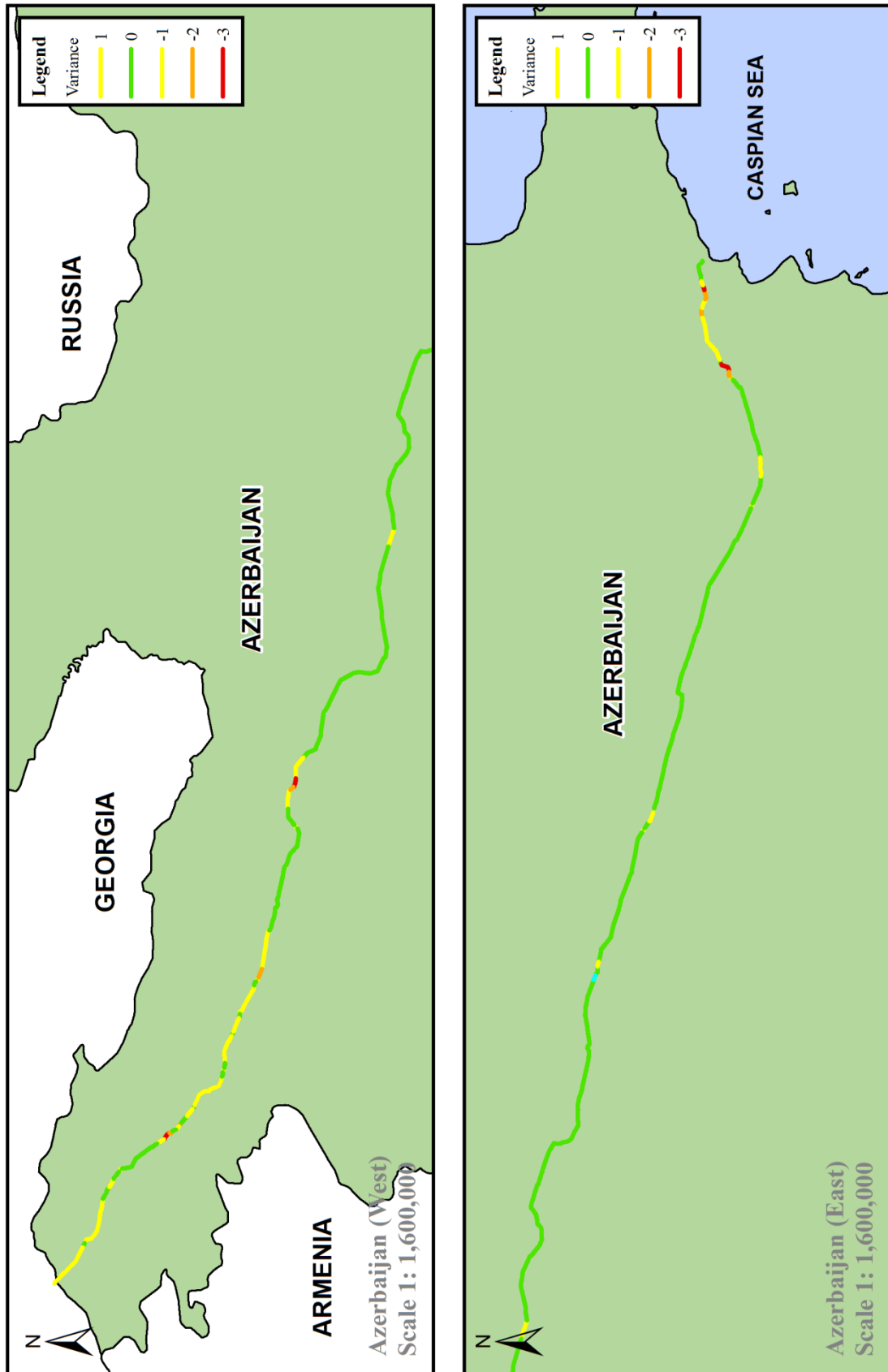
Map 6 – SRTM Digital Elevation Model

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Map 7 – Slope Analysis

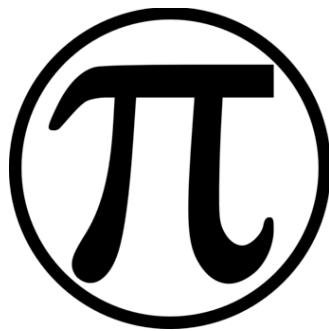


Map 8 – Soil Erosion Risk Assessment (Azerbaijan)



Map 9 – Soil Erosion Risk Variance (Azerbaijan)

Appendix E – Software Design Specification (SDS)



**PIPELINE INTEGRATED ENGINEERING ENVIRONMENT
(PIEE)
SOFTWARE DESIGN SPECIFICATION**

Revision 1.06



Executive Summary

This Software Design Specification (SDS) outlines the requirements and design of an implementation of an Advanced Engineering Geographical Information System (AEGIS) for the design of onshore pipelines. This implementation is the Pipeline Integrated Engineering Environment (PIEE). The proposal is to use an Agile based development strategy to deliver a phased solution of the system.

This document will be revised throughout the development of the system. The aim is that this specification will provide both a description of the system as issued and the plan for the next phase.



Glossary

Term	Description
Abstract Class	A class that cannot which cannot be instantiated directly. See feature Class.
AEGIS	Advanced Engineering Geographical Information System. A term defining engineering specific implementations of a GIS (Winning, 2015).
Feature	An instance of a feature class.
Feature Class	A class that can have instances. See Abstract Class. It is a model, polyline, point or polygon.
Function Code	Short name for a function, used in the use case flowcharts.
Function Name	Name of a code module which performs a method for a feature.
Function Type	Code module classification, allowing similar modules to be grouped together. (Model, Route, etc)
GIS	Geographical Information System.
Method	A subroutine associated with an object of a class that forms its interface through which the outside members of the class (other objects) can access its private members (mainly the encapsulated data)
Method Scope	Either Public (P) or Internal (I).
PIEE	Pipeline Integrated Engineering Environment. An AEGIS for the design of onshore pipelines.
SDS	Software Design Specification.



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FRONT MATTER

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1 Introduction

This Software Design Specification (SDS) is based on a template (Appleton, 1994) which is founded on a number of standard texts and standards, including IEEE-1016 for Software Designs, and IEEE-830 for Software Requirements. The template was selected, as it did not seek to assume or impose a particular software development methodology or paradigm, and places more emphasis on content rather than format.

This system has been developed in support of doctoral research undertaken into the development of an Advanced Engineering Geographical Information System (AEGIS) for pipelines (Winning, 2015).

1.1 Naming Convention

This specific implementation of the AEGIS is referred to as the Pipeline Integrated Engineering Environment (PIEE). The initial revision will be 1.00. Reserved words of the PIEE system (classes, attributes, etc) are formatted thus: **PIEEPoint**.

1.2 Defined Terms

Term	Description
AEGIS	Advanced Engineering Geographical Information System. A term defining engineering specific implementations of a GIS (Winning, 2015).
Function Code	Short name for a function, used in the use case flowcharts.
Function Name	Name of a code module which performs a method for a feature.
Function Type	Code module classification, allowing similar modules to be grouped together. (Model, Route, etc)
Method Scope	Either Public (P) or Internal (I).
PIEE	Pipeline Integrated Engineering Environment. An AEGIS for the design of onshore pipelines.
SDS	Software Design Specification.

1.3 Advanced Engineering Geographical Information System (AEGIS)

The term, Advanced Engineering Geographical Information System first appeared in the glossary of a standard Geographical Information System (GIS) text (Longley et al., 2010: xvii). While Longley introduced the term, they did not define it and it is interesting to note that although it appears in the glossary it is not mentioned elsewhere in the text. In addition, the term AEGIS fails to return anything in internet search engines or online journals, which would suggest that perhaps the authors saw this as an aspirational future

direction for GIS, challenging engineers to see the potential for the application of GIS within their own fields.

Since all GIS systems are designed to store, manage, retrieve data, and perform queries on geospatial data, an engineering GIS would need to do this with geospatial engineering data. However, to be 'advanced' it must be more than merely a repository for geospatial engineering data; indeed it must be capable of performing analytical and decision making functions within an engineering context whilst presenting the engineer with all the geospatial tools and functionality inherent in a GIS system. In the absence of a formal definition for an AEGIS system, it may be defined as:

- All the standard GIS functionality for geospatial data management, access, querying and analysis.
- A method of handling engineering data, including revision and versioning control of datasets.
- Provide specialist engineering geospatial and non-geospatial tools that are specific to the particular field of engineering, within the GIS environment.
- Reduce the interfaces between processes and provide data interoperability.

Based on these requirements, an AEGIS may therefore be defined as:

A single multi-discipline integrated system using an open industry standard schema providing all the standard GIS tools with the added functionality required to undertake the engineering and design of a specific engineering function.

The key component of this definition is that the system should be function and not discipline specific.

1.4 Scope

This SDS defines the design of an Advanced Engineering Geographical Information System (AEGIS) for onshore pipelines. It outlines the system design, identifying the key components, inputs, and outputs to enable development of the system. This SDS is used to support the development of the system. The intention is that the system will demonstrate the validity of the constructs, methods and processes of the system, in terms of an Information System (IS) artefact.

This document provides a high level overview of the system, in addition to providing the programmer with the details through a physical model, UML class diagrams, methods, function flowcharts, and data dictionaries.



1.5 Reference Documents

The development of the system is based on the following research.

- (Winning, 2009)** *PHASE - A Software Application to Perform the Preliminary Hydraulic Analysis and System Evaluation for Onshore Pipelines.* BEng(Hons) Mechanical Engineering Design Final Year Project, Buckinghamshire New University.
- (Winning, 2011)** *Improved Computational Method for the Estimation of the Friction Factor in Rough and Smooth Pipes for Single Phase Newtonian Fluids.* MEng (Hons) Mechanical Engineering Design Final Year Project, Buckinghamshire New University.
- (Winning and Coole, 2013)** Explicit friction factor accuracy and computational efficiency for turbulent flow in pipes. *Flow, Turbulence and Combustion*, 90, 1-27.
- (Winning, 2013b)** *Predicting Soil Erosion Risk for Onshore Pipelines Using Remote Sensed Data.* MSc Geographical Information Science Dissertation, Birkbeck, University of London.
- (Winning and Hann, 2014)** Modelling soil erosion risk for pipelines using remote sensed data. *Biosystems Engineering*, 127, 135-143.
- (Winning and Coole, 2015)** Improved method of determining friction factor in pipes. *International Journal of Numerical Methods for Heat & Fluid Flow*, 25.
- (Winning, 2015)** *Advanced Engineering Geographical Information Systems for Pipelines.* PhD Doctoral Thesis, Coventry University.

In addition, elements of the system and the underpinning research have been presented at the following conferences.

- (Winning, 2013a)** Pipeline design - Protecting the environment: application of GIS to pipeline route selection. Uganda Investment Forum - Driving Growth in Africa, 11th - 12th April 2013 2013a Kampala, Uganda. 11th - 12th April. Pipelines: Commonwealth Business Council. Available: [http://www.cbglobal.org/images/uploads/library/Uganda Investment Forum - Natural Resources - Keith Winning - CBI.pdf](http://www.cbglobal.org/images/uploads/library/Uganda_Investment_Forum_-_Natural_Resources_-_Keith_Winning_-_CBI.pdf).
- (Winning, 2014a)** Developing advanced engineering geographical information systems for pipelines. ESRI European Petroleum User Group Conference, 2014a London, UK. 6th - 7th November. ESRI. Available: http://proceedings.esri.com/library/userconf/epug14/papers/epug_2_0.pdf?bcsi_scan_2ceab535dd6db143=0&bcsi_scan_filename=epug_2_0.pdf.
- (Winning, 2014b)** Identifying soil erosion risk for onshore pipelines. ESRI European User Conference, 13th - 15th October, 2014 2014b Split, Croatia. 13th - 15th October. ESRI.
- (Winning, 2014c)** PODS - From design to operation. PODS User Conference, 2014c Houston, USA. 25th - 27th October. Pipeline Open Data Standards. Available: [http://pods.org/assets/file/2014%20K%20Winning%20PODS%202014%20\(Paper%20-%20Rev%204.5\).pdf](http://pods.org/assets/file/2014%20K%20Winning%20PODS%202014%20(Paper%20-%20Rev%204.5).pdf).



1.6 System Overview

The PIEE is designed to facilitate aspects of pipeline design across the fields of pipeline engineering, environmental engineering and engineering design. Key features of the system include:

- Pipeline hydraulics. By including preliminary pipeline hydraulics within the system, it is possible for the pipeline engineer to assess the impact of route selection on the hydraulic design of the system. It also enables the hydraulic engineer to quickly compare routes hydraulically and to determine the optimum combination of pipe size and compressor/pump station combinations for a specific route.
- Class location determination. Currently only the determination based on ASME B31.8 is available. This enables the engineer to accurately determine the code compliance requirements for the allocation of heavy wall pipe according to the population density for gas pipelines. Checks are available within the model to ensure compliance.
- Estimated soil erosion loss. This function enables the environmental engineer to perform a risk assessment of the potential for soil erosion for a given route. This allows the subsequent field investigation to be targeted to the areas of concern.
- Automated production of drawings, reports and schedules. The cost savings due to speed of production and the reduced burden on checking offset the design and maintenance of the PIEE system.

The overall use case diagram (Figure 1.1) shows the integrated approach and its application to the main stakeholders of the system.

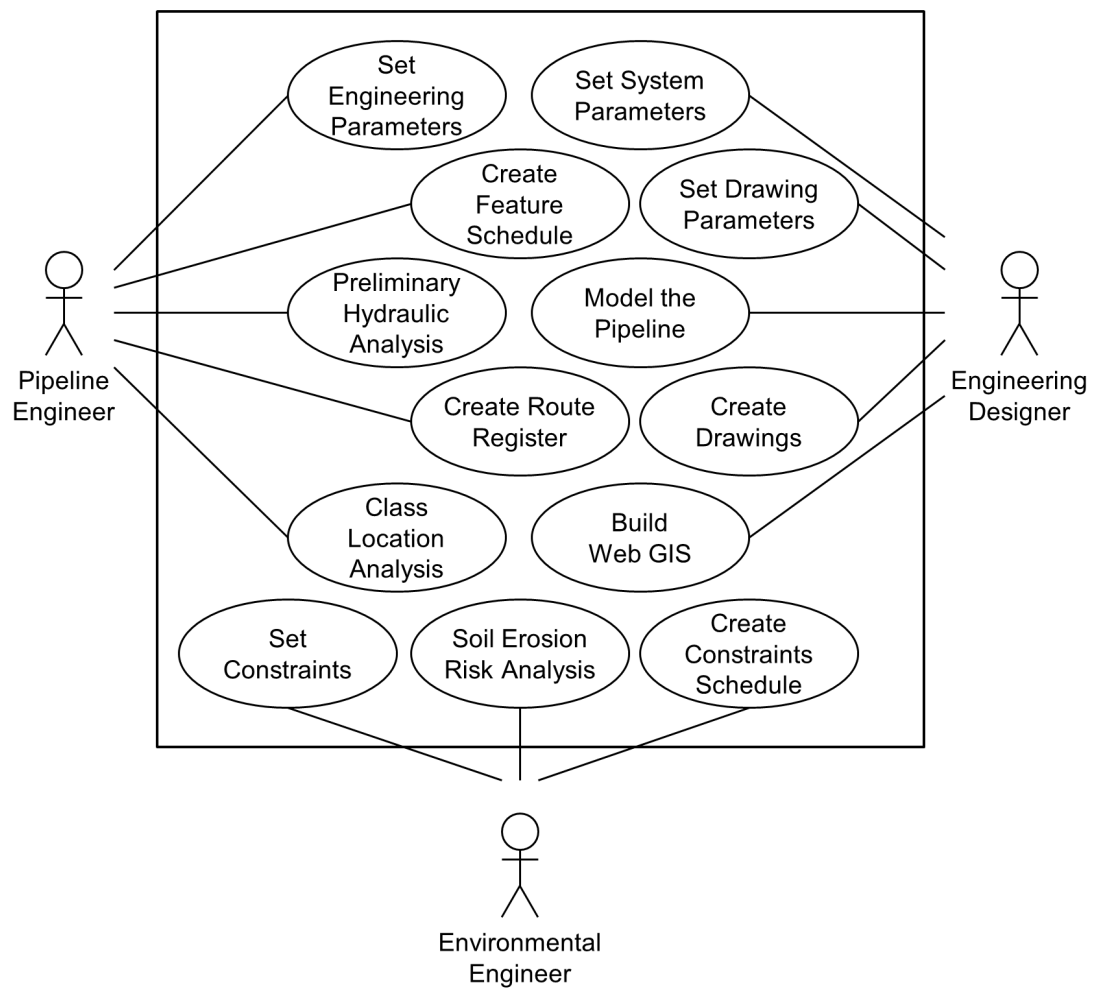


Figure 1.1 – PIEE Use Case Diagram

The main design considerations of the system (Table 1.1) are based in part on a quality function deployment (QFD) approach. This identified the key features for inclusion in the initial revision of the system.



Feature	Reason for Selection									
	Reduced Interfaces	Interoperability	Codes & Standards	Environmental	Route Selection	Cost Modelling	Increased efficiency	Improved quality	Reduced design cost	Improved PIM Data
Preliminary hydraulic analysis within the GIS environment	✓	✓			✓	✓	✓		✓	
Class location for gas pipelines	✓		✓		✓	✓	✓	✓	✓	
Identification of the potential soil erosion risk	✓			✓	✓	✓	✓		✓	
Production of alignment sheets		✓	✓		✓		✓	✓	✓	
Web hosted GIS model	✓	✓					✓			
As built documentation		✓					✓	✓		✓
PIM GIS Model	✓	✓	✓							✓

Table 1.1 – Selected Features for the AEGIS



2 Design Considerations

The design considerations are discussed in detail (Winning, 2015) and summarised below.

2.1 Assumptions and Dependences

Crossing Type	Description
acLib.vlx	AutoLISP library functions, written by Keith Winning.
DOSLib.arx	Robert McNeel AutoCAD Function Library

The PIEE needs to function within the current hardware and software environment. The current systems are using the Microsoft Windows 7 operation system on high end Dell workstations with 16Gb of RAM. The main engineering design tool is AutoCAD Civil 3D 2010, with a move towards AutoCAD Civil 3D 2015 imminent.

The current engineering design team is comprised of designers with a range of skills, experience and ability, with previous exposure to the use of automated design solutions. Given the teams experience with AutoCAD, the system will be designed to present the user with a system that conforms to the design principles of AutoCAD, to reduce the requirements for extensive training.

2.2 General Constraints

2.2.1 Standards

The system will conform to the following standards:

Number	Standard
ASME B31.8	Gas Transmission and Distribution Piping Systems
ASME B31.8S	Managing System Integrity of Gas Pipelines
BS 8888	Technical product documentation and specification

2.2.2 Resources

The aim is to be able to use the existing engineering design team with minimal additional training. This approach requires the system to utilize the existing geospatial engineering design software, AutoCAD Civil 3D 2010. However, it should be noted that the design team will be migrating to AutoCAD Civil 3D 2015 during the course of this development.

2.2.3 Hardware

Dell workstations with 16Gb of RAM.



2.2.4 Operating System

Microsoft Windows 7 Professional Service Pack 1.

2.2.5 Design Software Interface

AutoCAD Civil 3D 2010 and AutoCAD Civil 3D 2015.

2.2.6 Interoperability Requirements

PODS version 5.1.1.20130228.01. Ability to handle other pipeline data models and PODS data model versions also required.

2.3 Goals and Guidelines

The guidelines for the system are summarised as:

2.3.1 General

- QA/QC integrity of model data and processes.
- Functional rather than software centric design.
- Enable user to use tools of preference for data creation.
- Reduction in the number of interfaces.
- Reduce the cost and time to deliver the pipeline design.

2.3.2 Engineering

- Demonstrate the ability to perform engineering calculations within a GIS environment (pipeline hydraulics).
- Demonstrate the value of using GIS to solve engineering design (Class location requirements).
- Version control of route and associated attributes.

2.3.3 Environmental Engineering

- Demonstrate the ability to perform early environmental engineering solutions based on remote sensed data.

2.3.4 Engineering Design

- Automated production of key project deliverable design documents.
- Use of templates to automate initial design.
- Reduce manual checking of deliverable documents.

2.3.5 GIS

- Import and export of design, vendor and construction data.
- Validation of the model through the automated production of model validation documents.
- Web interface.

2.3.6 User Interface

- Intuitive, without replication of standard features.
- To retain the standard look and feel of the native interface (AutoCAD).

2.4 Development Methods

Peffer et al. propose a fuller Design Science Research Methodology (DSRM) process model (Figure 2.1). The model is structured, with the problem centred approach being the basis of the nominal sequential order, though the process may be initiated at a number of different start points. This approach was applied retrospectively to four case studies, each starting at a different point within the model. The DSRM proposed by Peffer et al. forms the basis of the overall methodology for the thesis.

This process model provides a holistic method for the thesis, with the creation and evaluation of the artefact being central to the method.

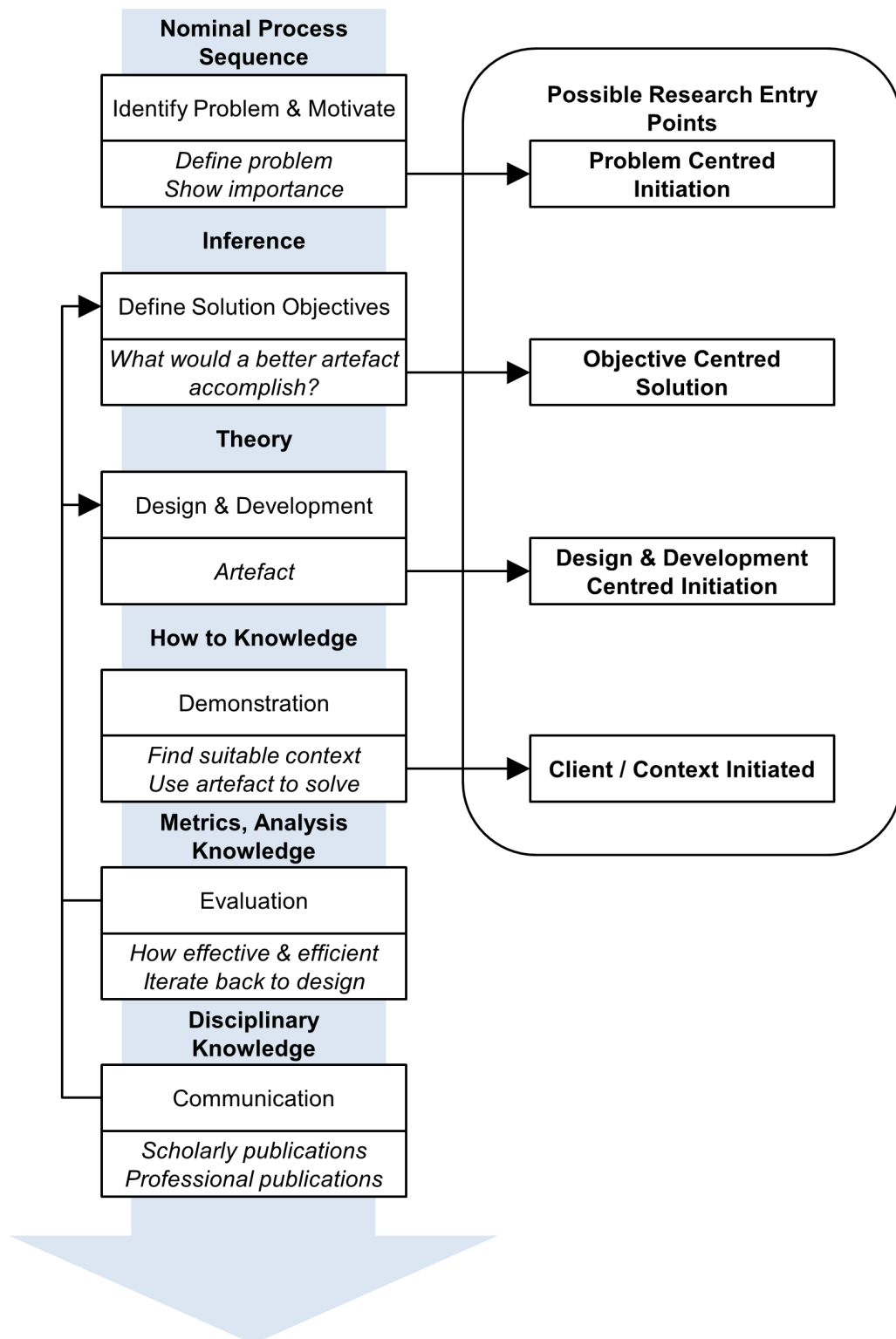


Figure 2.1 – Design Science Research Methodology Process Model

The methodology for the design, development and evaluation of the AEGIS is based on the DSRM process model, proposed by (Peffer et al., 2007: 58). This methodology identifies six stages, based on a problem centred approach:

1. Identify the problem. From a review of the current methods and process in the design of onshore pipelines, a research question was proposed and refined by the initial literature survey.
2. Define the objectives. From the literature survey the aim and objectives of the thesis have been defined.
3. Design and development. From the objectives identified, four key areas for further research were identified.
 - a. define the methodology for the thesis,
 - b. pipeline hydraulic simulation within the GIS environment,
 - c. estimation of the soil erosion risk from remote sensed data, and
 - d. automated production of deliverable documents.
4. Demonstration. This is achieved through the development of the artefact (software), demonstrating the validity of the constructs, models, methods and implementation. The requirements for the software are defined in this document.
5. Evaluation. The evaluation of the artefact, comparing it to other systems and processes currently in use and to the defined metrics specified in the SDS.
6. Communication.

2.5 Programming Language

Because of the selected host system (AutoCAD Civil 3D), the language used for the development is Visual LISP, an Autodesk proprietary language. This is a development of the Autodesk AutoLISP language based on the LISP language. Visual LISP is an integrated development environment (IDE) that includes a compiler, debugger, and other development tools to increase productivity. It adds more capabilities and extends the AutoLISP language to interact with objects using ActiveX. It also enables AutoLISP to respond to events through object reactors.

Unlike in ObjectARX, or VBA, each document opened in the Multiple Design Environment (MDE) has its own Visual LISP namespace and environment. A namespace is an insulated environment keeping AutoLISP routines that are specific to one document from having symbol or variable name and value conflicts with those in another document.



The conventions in this SDS follow the UML 2.0 standards (Fowler, 2004), while the function flowcharts are based on the UML activity diagram standard (Wieggers and Beatty, 2013). The class diagrams have been created using Violet UML Editor, Version 2.0.1 (available at: <http://violet.sourceforge.net/>).



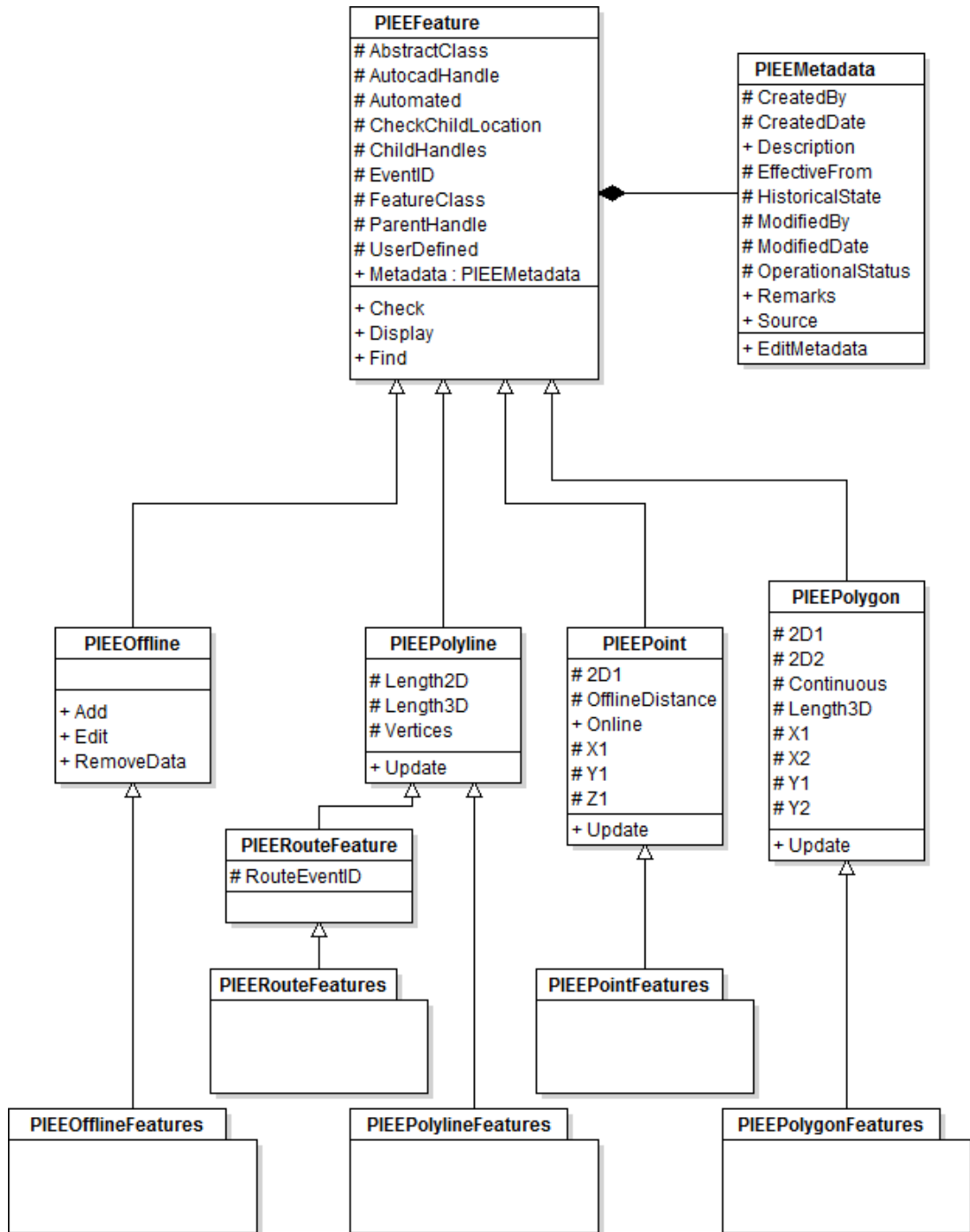
3 Detailed System Design

3.1 Data Model

The PIEE data model is based on the PODS data model with changes to support the additional features of the PIEE system.



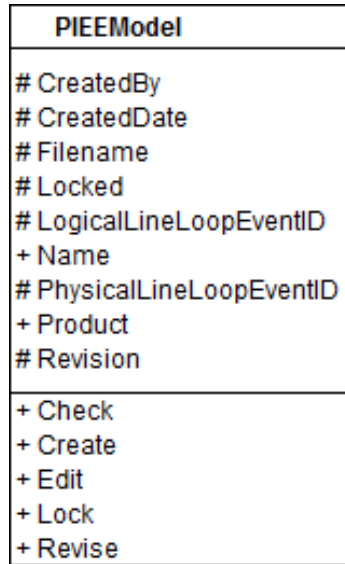
3.2 Abstract Classes



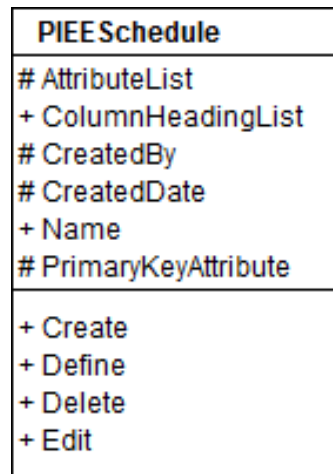


3.3 Feature Classes

3.3.1 PIEEModel Feature Class

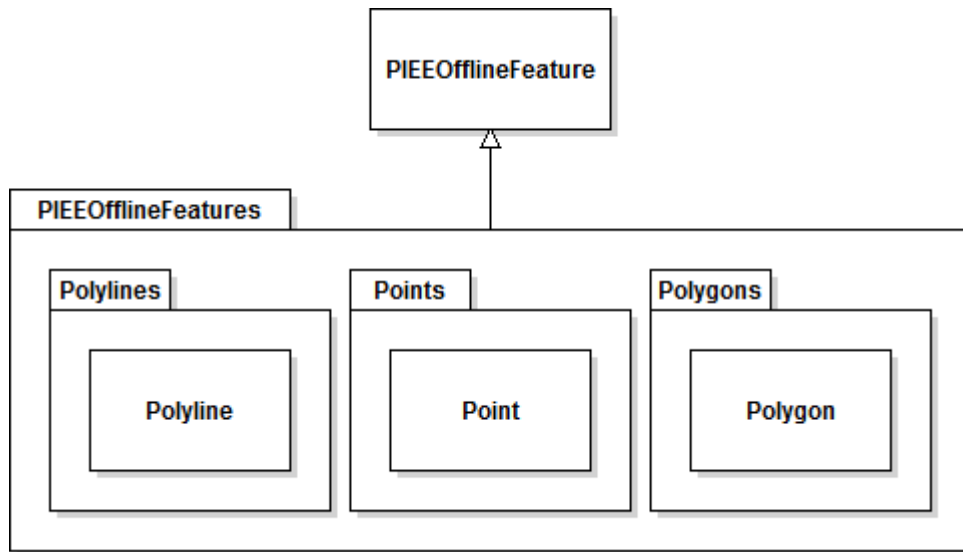


3.3.2 PIEESchedule Feature Class

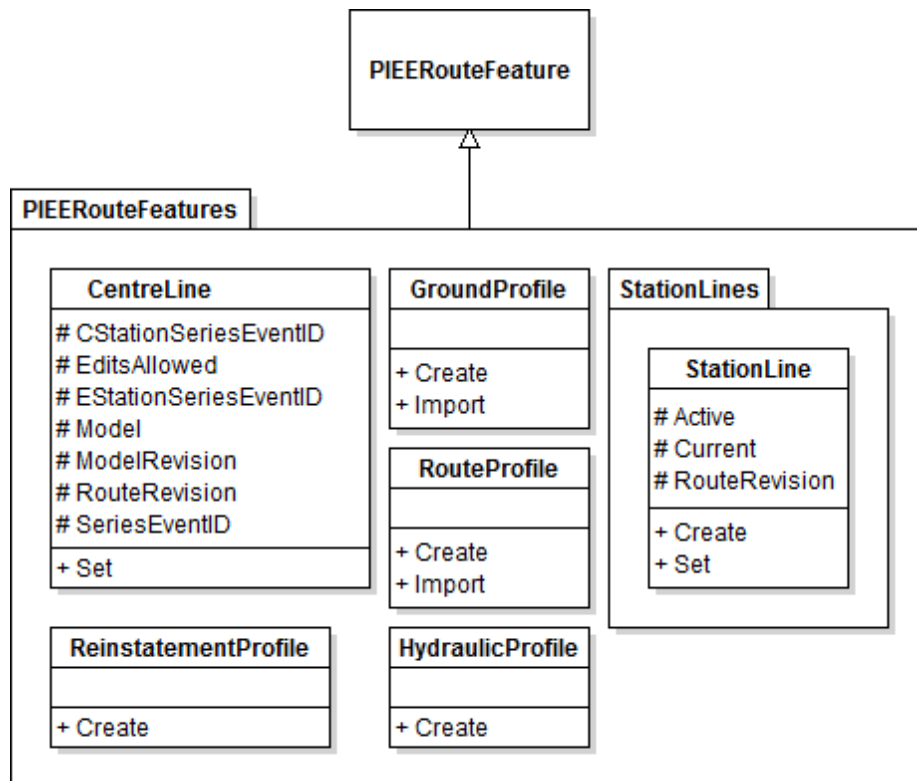




3.3.3 PIEEOffline Feature Class

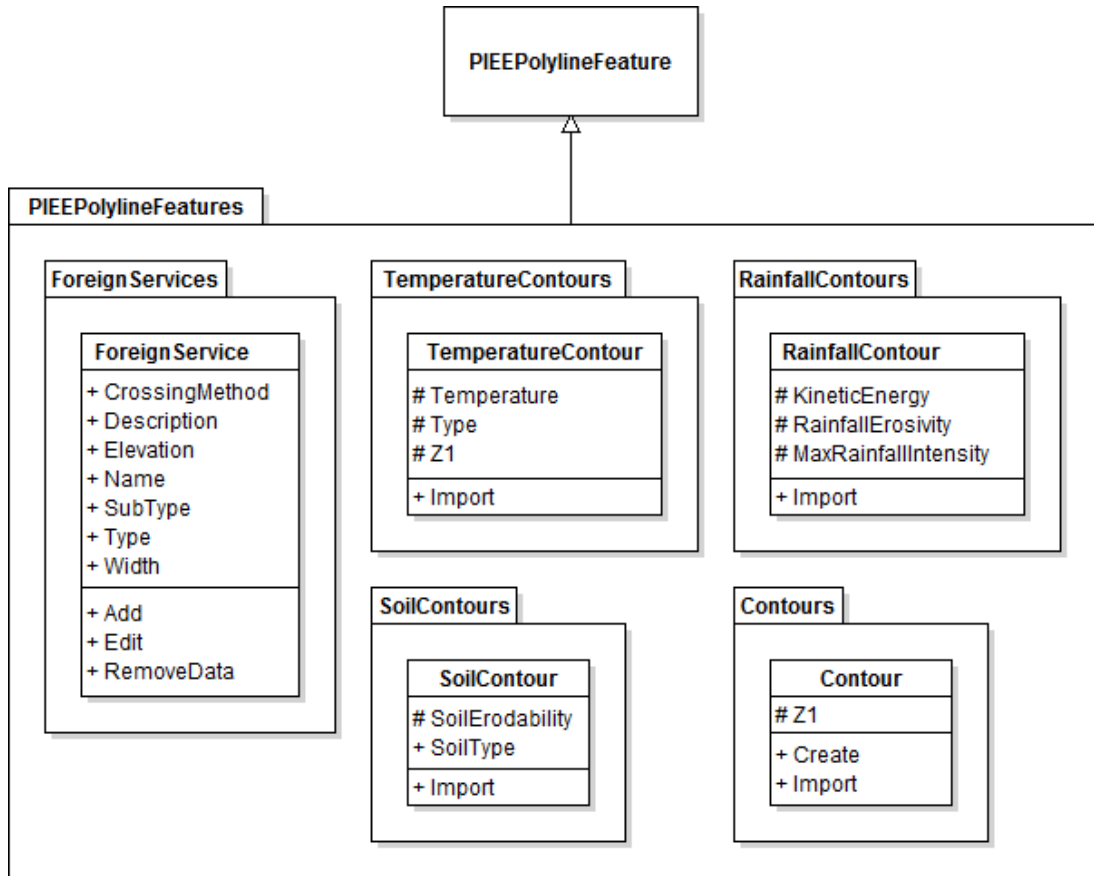


3.3.4 PIEERoute Feature Class



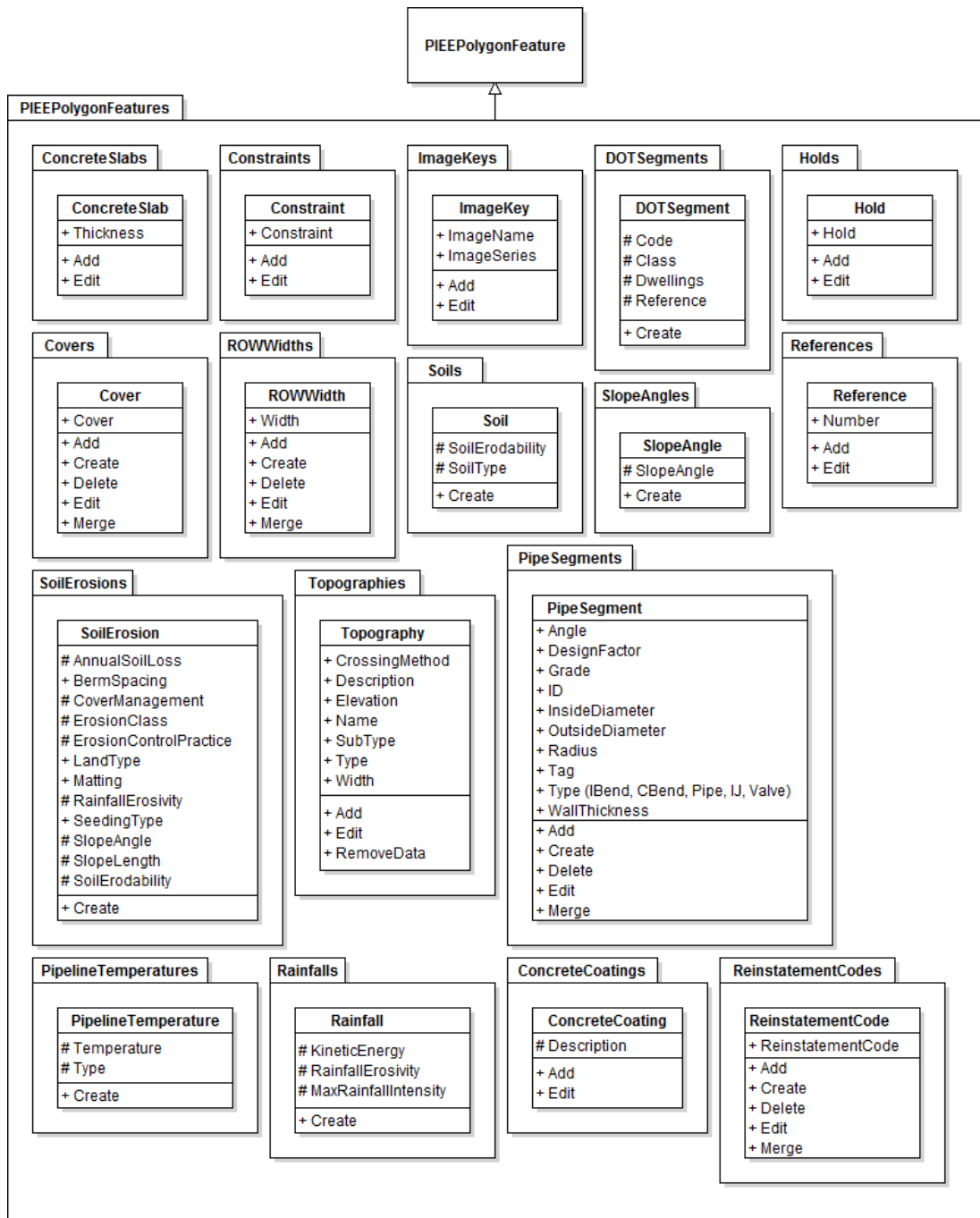


3.3.5 PIEEPolyline Feature Class



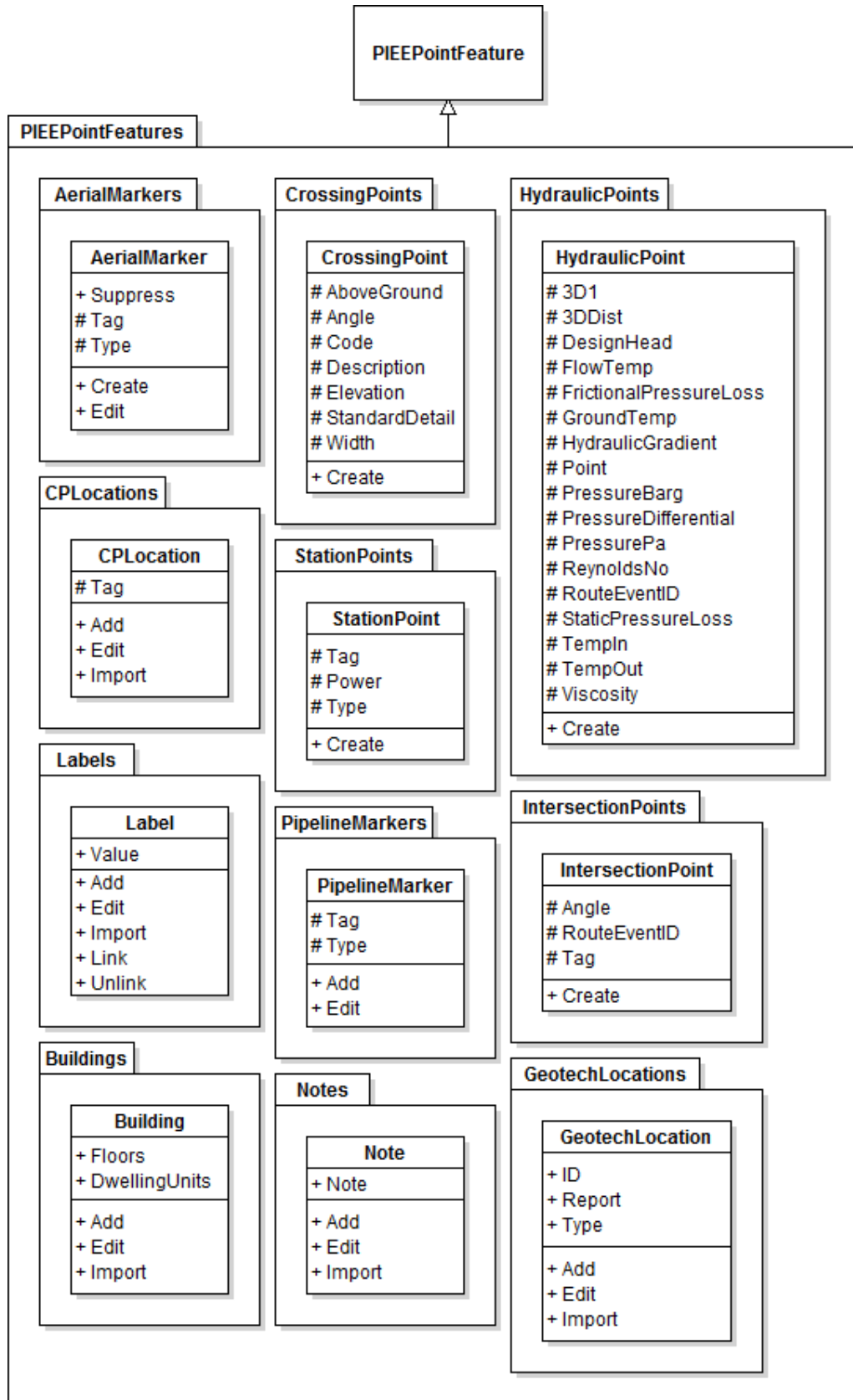


3.3.6 PIEEPolygon Feature Class



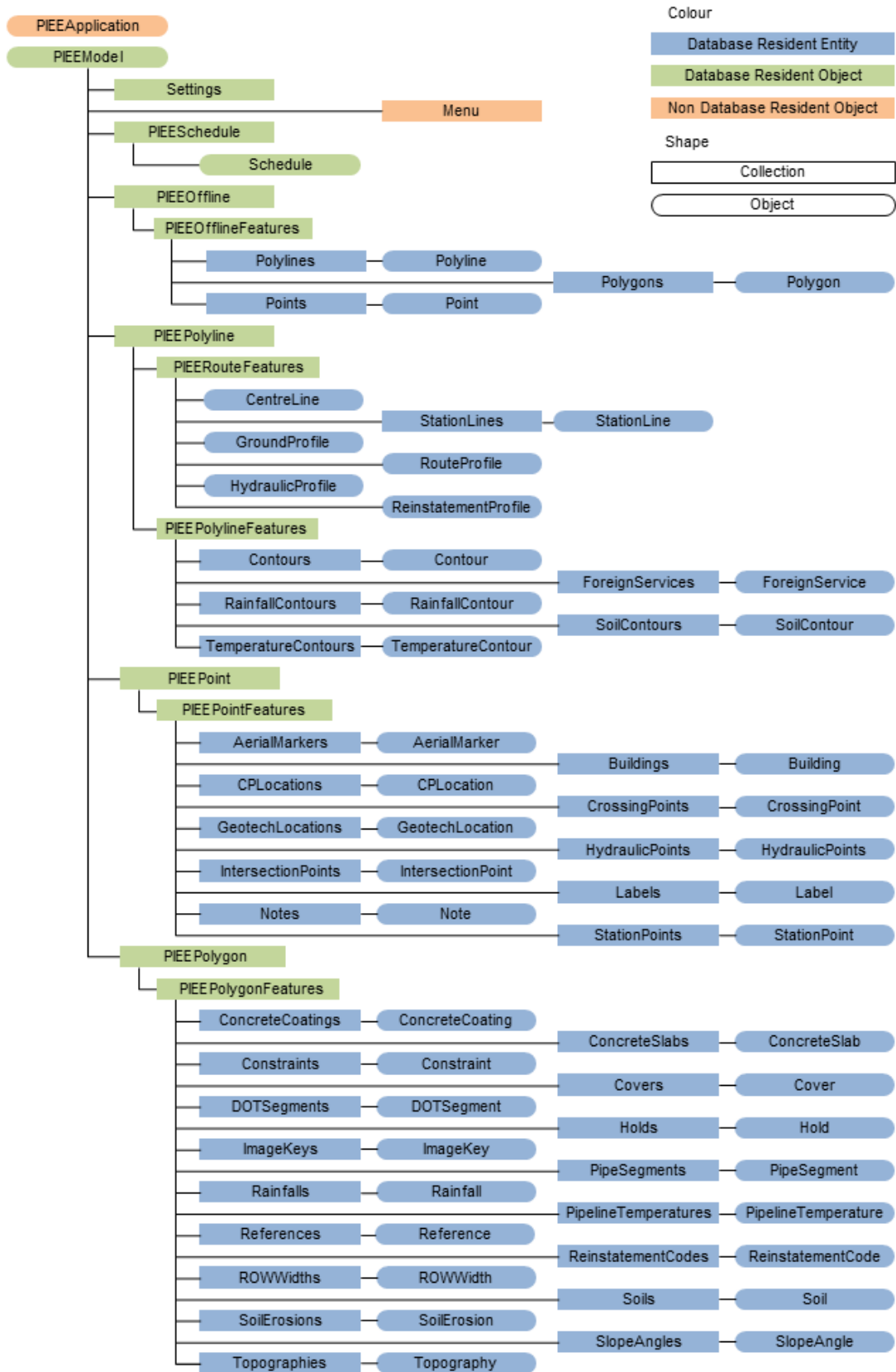


3.3.7 PIEEPoint Feature Class





3.4 Object Model





3.5 Data Types

Type	Description
GUID	Global Unique Identifier for the entity. 32 character string of hexadecimal numbers enclosed in curly braces.
Real	A real is a number containing a decimal point. Numbers between -1 and 1 must contain a leading zero. Real numbers are stored in double-precision floating-point format, providing at least 14 significant digits of precision.
Integer	Integers are whole numbers that do not contain a decimal point. AutoLISP integers are 32-bit signed numbers with values ranging from +2,147,483,647 to -2,147,483,648. (Note, however, that the getint function only accepts 16-bit numbers ranging from +32767 to -32768.)
String	A string is a group of characters surrounded by quotation marks. Within quoted strings the backslash (\) character allows control characters (or escape codes) to be included.
Boolean	T or NIL

3.6 Data Dictionary

3.6.1 PIEEModel

Attribute:	# CreatedBy	Calculated:	Y	Domain:	N
Description:	Username of the creator of the model.				
Set by:	PIEEModel.Create	Data Type:	String		

Attribute:	# CreatedDate	Calculated:	Y	Domain:	N
Description:	Date model created.				
Set by:	PIEEModel.Create	Data Type:	String		

Attribute:	# Filename	Calculated:	Y	Domain:	N
Description:	Qualified filename of the AutoCAD file of the PIEE model.				
Set by:	PIEEModel.Create, PIEEModel.Revise	Data Type:	String		

Attribute:	# Locked	Calculated:	Y	Domain:	Y
Description:	Flag to enable model route editing.				
Set by:	PIEEModel.Create, PIEEModel.Revise, PIEEModel.Lock	Data Type:	Boolean		

Attribute:	# LogicalLineLoopEventID	Calculated:	Y	Domain:	N
Description:	Identifier for the logical lineloop event.				
Set by:	PIEEModel.Create	Data Type:	GUID		

Attribute:	+ Name	Calculated:	Y	Domain:	N
Description:	PIEE Model Name.				
Set by:	PIEEModel.Create, PIEEModel.Edit	Data Type:	String		

Attribute:	# PhysicalLineLoopEventID	Calculated:	Y	Domain:	N
Description:	Identifier for the physical lineloop event.				
Set by:	PIEEModel.Create	Data Type:	GUID		

Attribute:	+ Product	Calculated:	N	Domain:	Y
Description:	Pipeline product (e.g. Oil or Gas).				
Set by:	PIEEModel.Create, PIEEModel.Edit	Data Type:	String		

Attribute:	# Revision	Calculated:	Y	Domain:	N
Description:	The model revision number.				
Set by:	PIEEModel.Create, PIEEModel.Revise	Data Type:	Integer		

3.6.2 PIEESchedule

Attribute:	# AttributeList	Calculated:	Y	Domain:	N
Description:	List of attributes in the format: FeatureClass.Attribute1;FeatureClass.Attribute2;FeatureClass.Attribute3				
Set by:	PIEESchedule.Define	Data Type:	String		

Attribute:	+ ColumnHeadingList	Calculated:	N	Domain:	N
Description:	List of column headings in the format: ColumnHeading1;ColumnHeading2;ColumnHeading3				
Set by:	PIEESchedule.Define	Data Type:	String		

Attribute:	# CreatedBy	Calculated:	Y	Domain:	N
Description:	Username of the creator of the schedule definition.				
Set by:	PIEESchedule.Define	Data Type:	String		

Attribute:	# CreatedDate	Calculated:	Y	Domain:	N
Description:	Date schedule definition created in the format dd/mm/yyyy.				
Set by:	PIEESchedule.Define	Data Type:	String		

Attribute:	+ Name	Calculated:	N	Domain:	N
Description:	Schedule definition name.				
Set by:	PIEESchedule.Define	Data Type:	String		

Attribute:	# PrimaryKeyAttribute	Calculated:	Y	Domain:	N
Description:	Attribute that will be used to sort and link attributes from different feature classes in the schedule definition.				
Set by:	PIEESchedule.Define	Data Type:	String		

3.6.3 PIEEFeature

Attribute:	# AbstractClass	Calculated:	Y	Domain:	Y
Description:	Abstract class type – Point, Polyline or Polygon.				
Set by:	PIEEFeature.Define	Data Type:	String		

Attribute:	# AutocadHandle	Calculated:	Y	Domain:	N
Description:	AutoCAD handle of the entity – Hexidecimal number prefixed with '#’.				
Set by:	PIEEFeature.Add	Data Type:	String		



Attribute:	# Automated	Calculated:	Y	Domain:	Y
Description:	Flag indicating that the feature can only be created programmatically.				
Set by:	PIEEFeature.Define	Data Type:	Boolean		

Attribute:	# CheckChildLocation	Calculated:	Y	Domain:	Y
Description:	Flag indicating that the position of the parent entity has been revised and that child entities require checking.				
Set by:	PIEEFeature.Check	Data Type:	Boolean		

Attribute:	# ChildHandles	Calculated:	Y	Domain:	N
Description:	Semicolon delimited string of child handles (each prefixed with '#').				
Set by:	PIEEFeature.Link, PIEEFeature.Unlink	Data Type:	String		

Attribute:	# EventID	Calculated:	Y	Domain:	N
Description:	Global Unique Identifier for the entity. 32 character string of 33 hexadecimal numbers enclosed in curly braces.				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	GUID		

Attribute:	# FeatureClass	Calculated:	Y	Domain:	N
Description:	Feature class name.				
Set by:	PIEEFeature.Define	Data Type:	String		

Attribute:	# ParentHandle	Calculated:	Y	Domain:	N
Description:	The AutoCAD handle of the parent entity prefixed with '#'. Only populated for child entities.				
Set by:	PIEEFeature.Link, PIEEFeature.Unlink	Data Type:	String		

Attribute:	# UserDefined	Calculated:	Y	Domain:	N
Description:	Flag indicating user defined feature class.				
Set by:	PIEEFeature.Define	Data Type:	Boolean		

3.6.4 PIEEMetadata

Attribute:	# CreatedBy	Calculated:	Y	Domain:	N
Description:	Username of the creator of the record.				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	String		

Attribute:	# CreatedDate	Calculated:	Y	Domain:	N
Description:	Date record created in the format dd/mm/yyyy.				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	String		

Attribute:	+ Description	Calculated:	N	Domain:	N
Description:	Description of the record.				
Set by:	PIEEFeature.EditMetadata	Data Type:	String		

Attribute:	# EffectiveFrom	Calculated:	Y	Domain:	N
Description:	Date the record is effective from, in the format dd/mm/yyyy.				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	String		

Attribute:	# HistoricalState	Calculated:	Y	Domain:	Y
Description:	Data status (Design, Construction, As-built).				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	String		

Attribute:	# ModifiedBy	Calculated:	Y	Domain:	N
Description:	Username of the editor of the record.				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	String		

Attribute:	# ModifiedDate	Calculated:	Y	Domain:	N
Description:	Date record modified in the format dd/mm/yyyy.				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	String		

Attribute:	# OperationalStatus	Calculated:	Y	Domain:	Y
Description:	Operational Status of pipeline (Active, Inactive)				
Set by:	PIEEFeature.Add, PIEEFeature.Create	Data Type:	String		

Attribute:	+ Remarks	Calculated:	N	Domain:	N
Description:	Data remarks, notes – For example: why a feature has been suppressed.				
Set by:	PIEEFeature.EditMetadata	Data Type:	String		

Attribute:	+ Source	Calculated:	N	Domain:	N
Description:	Data source/supplier.				
Set by:	PIEEFeature.EditMetadata	Data Type:	String		

3.6.5 PIEEOfflineFeature

Offline features. There are no additional feature attributes.

3.6.6 PIEERouteFeature

Attribute:	# RouteEventID	Calculated:	Y	Domain:	N
Description:	RouteEventID of the CentreLine that was used to create the route feature.				
Set by:	PIEERouteFeature.Create	Data Type:	GUID		

3.6.7 PIEEPolylineFeature

Attribute:	# Length2D	Calculated:	Y	Domain:	N
Description:	Plan (2D) length of the polyline entity in metres.				
Set by:	PIEEPolyline.Create, PIEEPolyline.Edit	Data Type:	Real		

Attribute:	# Length3D	Calculated:	Y	Domain:	N
Description:	Slope (3D) length of the polyline entity in metres.				
Set by:	PIEEPolyline.Create, PIEEPolyline.Edit	Data Type:	Real		

Attribute:	# Vertices	Calculated:	Y	Domain:	N
Description:	Number of vertices for the polyline entity.				
Set by:	PIEEPolyline.Create, PIEEPolyline.Edit	Data Type:	Integer		

3.6.8 PIEEPointFeature

Attribute:	# 2D1	Calculated:	Y	Domain:	N
Description:	2D chainage of the point feature in metres.				
Set by:	PIEEPoint.Add, PIEEPoint.Create, PIEEPoint.Edit, PIEEPoint.Import	Data Type:	Real		

Attribute:	# OfflineDistance	Calculated:	Y	Domain:	N
Description:	Distance in metres from the point feature to the route StationLine, perpendicular to the StationLine.				
Set by:	PIEEPoint.Add, PIEEPoint.Create, PIEEPoint.Edit, PIEEPoint.Import	Data Type:	Real		

Attribute:	+ Online	Calculated:	Y	Domain:	Y
Description:	Flag indicating the point feature is attached to the route StationLine.				
Set by:	PIEEPoint.Add, PIEEPoint.Create, PIEEPoint.Edit, PIEEPoint.Import	Data Type:	Boolean		

Attribute:	# X1	Calculated:	Y	Domain:	N
Description:	Easting coordinate of the point feature in metres.				
Set by:	PIEEPoint.Add, PIEEPoint.Create, PIEEPoint.Edit, PIEEPoint.Import	Data Type:	Real		



Attribute:	# Y1	Calculated:	Y	Domain:	N
Description:	Northing coordinate of the point feature in metres.				
Set by:	PIEERPoint.Add, PIEERPoint.Create, PIEERPoint.Edit, PIEERPoint.Import	Data Type:	Real		

Attribute:	# Z1	Calculated:	Y	Domain:	N
Description:	Elevation of the point feature in metres.				
Set by:	PIEERPoint.Add, PIEERPoint.Create, PIEERPoint.Edit, PIEERPoint.Import	Data Type:	Real		

3.6.9 PIEERPolygonFeature

Attribute:	# 2D1	Calculated:	Y	Domain:	N
Description:	Start plan (2D) chainage of the feature in metres.				
Set by:	PIEERPolygon.Add, PIEERPolygon.Create, PIEERPolygon.Delete, PIEERPolygon.Edit	Data Type:	Real		

Attribute:	# 2D2	Calculated:	Y	Domain:	N
Description:	End plan (2D) chainage of the feature in metres.				
Set by:	PIEERPolygon.Add, PIEERPolygon.Create, PIEERPolygon.Delete, PIEERPolygon.Edit	Data Type:	Real		

Attribute:	# Continuous	Calculated:	Y	Domain:	Y
Description:	Flag set to indicate that the feature data is continuous. If NIL data is discrete.				
Set by:	PIEERPolygon.Define	Data Type:	Boolean		

Attribute:	# Length3D	Calculated:	Y	Domain:	N
Description:	Slope (3D) length of the feature in metres.				
Set by:	PIEERPolygon.Add, PIEERPolygon.Create, PIEERPolygon.Delete, PIEERPolygon.Edit	Data Type:	Real		

Attribute:	# X1	Calculated:	Y	Domain:	N
Description:	Start easting coordinate in metres of the feature.				
Set by:	PIEERPolygon.Add, PIEERPolygon.Create, PIEERPolygon.Delete, PIEERPolygon.Edit	Data Type:	Real		

Attribute:	# X2	Calculated:	Y	Domain:	N
Description:	End easting coordinate in metres of the feature.				
Set by:	PIEERPolygon.Add, PIEERPolygon.Create, PIEERPolygon.Delete, PIEERPolygon.Edit	Data Type:	Real		



Attribute:	# Y1	Calculated:	Y	Domain:	N
Description:	Start northing coordinate in metres of the feature.				
Set by:	PIEEPolygon.Add, PIEEPolygon.Create, PIEEPolygon.Delete, PIEEPolygon.Edit	Data Type:	Real		

Attribute:	# Y2	Calculated:	Y	Domain:	N
Description:	End northing coordinate in metres of the feature.				
Set by:	PIEEPolygon.Add, PIEEPolygon.Create, PIEEPolygon.Delete, PIEEPolygon.Edit	Data Type:	Real		

3.6.10 PIEEOfflineFeatures

3.6.10.1 Polyline

Offline polyline feature. There are no additional feature attributes.

3.6.10.2 Polygon

Offline polygon feature. There are no additional feature attributes.

3.6.10.3 Point

Offline point feature. There are no additional feature attributes.

3.6.11 PIEERouteFeatures



3.6.11.1 CentreLine

This feature is the plan (2D) active CentreLine for the current revision of the model. It is comprised of straight line segments between intersection points. Only one CentreLine may reside in a model file.

Attribute:	# CstationSeriesEventID	Calculated:	Y	Domain:	N
Description:	Unique identifier for all revisions of the model.				
Set by:	Centreline.Set	Data Type:	GUID		

Attribute:	# EditsAllowed	Calculated:	Y	Domain:	Y
Description:	Flag indicating the editing is allowed.				
Set by:	PIEEModel.Lock	Data Type:	Boolean		

Attribute:	# EstationSeriesEventID	Calculated:	Y	Domain:	N
Description:					
Set by:	Centreline.Set	Data Type:	GUID		

Attribute:	# Model	Calculated:	Y	Domain:	N
Description:	Model Name.				
Set by:	Centreline.Set	Data Type:	String		

Attribute:	# ModelRevision	Calculated:	Y	Domain:	N
Description:	Model revision for the centre line. Format is major.minor revision number.				
Set by:	Centreline.Set	Data Type:	String		

Attribute:	# RouteRevision	Calculated:	Y	Domain:	N
Description:	Unique identifier for the current revision of the model. Maps to the PODS 'Engineering Station Series'.				
Set by:	Centreline.Set	Data Type:	GUID		

Attribute:	# SeriesEventID	Calculated:	Y	Domain:	N
Description:	Unique identifier for the current revision of the model. Maps to the PODS 'Continuous Station Series'.				
Set by:	Centreline.Set	Data Type:	GUID		



3.6.11.2 StationLine

This feature is a plan (2D) polyline based on a CentreLine with horizontal bends added. It is used for deriving the stationing (chainage calculation) for the model. Any number of StationLines may reside in a model. The latest one, based on the CentreLine has its #Current attribute set to T, all others are set to NIL. Any StationLine may be used for stationing (chainage calculation) by setting its #Active attribute to T. This sets the #Active attribute to NIL on all other StationLines.

Attribute:	# Active	Calculated:	Y	Domain:	Y
Description:	Flag to indicate the active StationLine for stationing (chainage calculation).				
Set by:	PIEERouteFeature.Create, StationLine.Set	Data Type:	Boolean		

Attribute:	# Current	Calculated:	Y	Domain:	Y
Description:	Flag to indicate the current (latest) StationLine based on the CentreLine.				
Set by:	PIEERouteFeature.Create, StationLine.Set	Data Type:	Boolean		

Attribute:	# RouteRevision	Calculated:	Y	Domain:	N
Description:	Unique identifier for the current revision of the model. Maps to the PODS 'Engineering Station Series'.				
Set by:	PIEERouteFeature.Create	Data Type:	GUID		

3.6.11.3 GroundProfile

This feature is the 3D representation of the ground profile and is created from the intersection of the StationLine and the contours. There are no additional feature attributes.

3.6.11.4 RouteProfile

This feature is the 3D representation of the route and is created from the GroundProfile. There are no additional feature attributes.

3.6.11.5 HydraulicProfile

This feature is created from the RouteProfile. It represents a simplified version of the RouteProfile. There are no additional feature attributes.

3.6.11.6 ReinstatementProfile

This feature is created from the GroundProfile. It represents a simplified version of the GroundProfile. There are no additional feature attributes.



3.6.12 PEEPolylineFeatures

3.6.12.1 Contour

Feature representing the digital elevation model (topography).

Attribute:	# Z1	Calculated:	Y	Domain:	N
Description:	The elevation in metres for the contour.				
Set by:	Contour.Create, Contour.Import	Data Type:	Real		

3.6.12.2 ForeignService

Feature representing an existing or planned foreign service. Used to create CrossingPoints at the intersection of the StationLine and the ForeignService feature. Refer to Appendix 4.1 for Foreign Service codes.

Attribute:	+ CrossingMethod	Calculated:	Y	Domain:	Y
Description:	Foreign Service crossing method code (see Appendix 4.1).				
Set by:	ForeignService.Add, ForeignService.Edit	Data Type:	String		

Attribute:	+ Description	Calculated:	Y	Domain:	Y
Description:	Foreign Service description.				
Set by:	ForeignService.Add, ForeignService.Edit	Data Type:	String		

Attribute:	+ Elevation	Calculated:	Y	Domain:	N
Description:	Elevation or depth of the Foreign Service.				
Set by:	ForeignService.Add, ForeignService.Edit	Data Type:	Real		

Attribute:	+ Name	Calculated:	N	Domain:	N
Description:	Name of the Foreign Service.				
Set by:	ForeignService.Add, ForeignService.Edit	Data Type:	String		

Attribute:	+ SubType	Calculated:	Y	Domain:	Y
Description:	Foreign Service sub type code (see Appendix 4.1).				
Set by:	ForeignService.Add, ForeignService.Edit	Data Type:	String		

Attribute:	+ Type	Calculated:	Y	Domain:	Y
Description:	Foreign Service sub type code (see Appendix 4.1).				
Set by:	ForeignService.Add, ForeignService.Edit	Data Type:	String		



Attribute:	+ Width	Calculated:	N	Domain:	N
Description:	Width (diameter) of the Foreign Service in metres.				
Set by:	ForeignService.Add, ForeignService.Edit	Data Type:	Real		

3.6.12.3 Rainfall Contour

Feature representing rainfall data.

Attribute:	# KineticEnergy	Calculated:	Y	Domain:	N
Description:	Kinetic Energy I component of the Rainfall Erosivity Equation (MJ/ha.mm)				
Set by:	RainfallContour.Create	Data Type:	Real		

Attribute:	# RainfallErosivity	Calculated:	Y	Domain:	N
Description:	Rainfall Erosivity I component of the Universal Soil Loss Equation (MJ.mm/ha.h)				
Set by:	RainfallContour.Create	Data Type:	Real		

Attribute:	# MaxRainfallIntensity	Calculated:	Y	Domain:	N
Description:	Maximum Rainfall Intensity (I30) component of the Rainfall Erosivity Equation (mm/h)				
Set by:	RainfallContour.Create	Data Type:	Real		

3.6.12.4 Soil Contour

Feature representing soil data.

Attribute:	# SoilErodability	Calculated:	Y	Domain:	N
Description:	Soil Erodability (K) component of the Universal Soil Loss Equation (h/MJ.mm)				
Set by:	SoilContour.Import	Data Type:	Real		

Attribute:	# SoilType	Calculated:	Y	Domain:	Y
Description:	Soil Type				
Set by:	SoilContour.Import	Data Type:	Real		

3.6.12.5 Temperature Contour

Feature representing the temperature range.

Attribute:	# Temperature	Calculated:	Y	Domain:	N
Description:	Temperature (in °C, rounded to the nearest 0.1°C)				
Set by:	TemperatureContour.Import	Data Type:	Real		



Attribute:	# Type	Calculated:	Y	Domain:	Y
Description:	Temperature type, high or low				
Set by:	TemperatureContour.Import	Data Type:	Boolean		

Attribute:	# Z1	Calculated:	Y	Domain:	N
Description:	The elevation in metres for the temperature contour.				
Set by:	TemperatureContour.Import	Data Type:	Real		

3.6.13 PIIEPPointFeatures

3.6.13.1 AerialMarker

Point feature representing a pipeline Aerial Marker.

Attribute:	+ Suppress	Calculated:	Y	Domain:	Y
Description:	Flag indicating that aerial marker should be suppressed.				
Set by:	AerialMarker.Create, AerialMarker.Edit	Data Type:	Boolean		

Attribute:	+ Tag	Calculated:	Y	Domain:	Y
Description:	Aerial marker tag.				
Set by:	AerialMarker.Create, AerialMarker.Edit	Data Type:	String		

Attribute:	+ Type	Calculated:	Y	Domain:	Y
Description:	Aerial marker type.				
Set by:	AerialMarker.Create, AerialMarker.Edit	Data Type:	String		

3.6.13.2 Building

Point feature representing a building.

Attribute:	+ Floors	Calculated:	N	Domain:	N
Description:	Number of floors in building.				
Set by:	Building.Add, Building.Edit, Building.Import	Data Type:	Real		

Attribute:	+ DwellingUnits	Calculated:	N	Domain:	N
Description:	Number of dwelling units in building.				
Set by:	Building.Add, Building.Edit, Building.Import	Data Type:	Real		



3.6.13.3 CPLocation

Point feature representing a pipeline cathodic protection location.

Attribute:	+ Tag	Calculated:	Y	Domain:	Y
Description:	Cathodic protection location tag.				
Set by:	AerialMarker.Create, AerialMarker.Edit	Data Type:	String		

3.6.13.4 CrossingPoint

Point feature representing a crossing location, inserted on the intersection of the StationLine and Topography or ForeignService feature.

Attribute:	# AboveGround	Calculated:	Y	Domain:	Y
Description:	Flag indicating if the crossing is above ground.				
Set by:	CrossingPoint.Create	Data Type:	Boolean		

Attribute:	# Angle	Calculated:	Y	Domain:	N
Description:	Angle in degrees of intersection between the pipeline and the crossed feature.				
Set by:	CrossingPoint.Create	Data Type:	Real		

Attribute:	# Code	Calculated:	Y	Domain:	Y
Description:	Crossing point code.				
Set by:	CrossingPoint.Create	Data Type:	String		

Attribute:	# Description	Calculated:	Y	Domain:	N
Description:	Physical description of the crossed feature. Inherited from the crossing feature.				
Set by:	CrossingPoint.Create	Data Type:	String		

Attribute:	# Elevation	Calculated:	Y	Domain:	N
Description:	Height or depth in metres of the crossed feature. Inherited from the crossing feature.				
Set by:	CrossingPoint.Create	Data Type:	Real		

Attribute:	# StandardDetail	Calculated:	Y	Domain:	N
Description:	Reference to the standard detail for the crossing type.				
Set by:	CrossingPoint.Create	Data Type:	String		



Attribute:	# Width	Calculated:	Y	Domain:	N
Description:	Width of the crossed feature in metres, inherited from the crossing feature. Only applies to foreign service crossings.				
Set by:	CrossingPoint.Create	Data Type:	Real		

3.6.13.5 GeotechLocation

Point feature representing a geotechnical sample location.

Attribute:	+ ID	Calculated:	Y	Domain:	N
Description:	Geotechnical sample location identification code.				
Set by:	GeotechLocation.Add, GeotechLocation.Edit, GeotechLocation.Import	Data Type:	String		

Attribute:	+ Report	Calculated:	Y	Domain:	N
Description:	Geotechnical sample location report reference number.				
Set by:	GeotechLocation.Add, GeotechLocation.Edit, GeotechLocation.Import	Data Type:	String		

Attribute:	+ Type	Calculated:	Y	Domain:	Y
Description:	Geotechnical sample type code.				
Set by:	GeotechLocation.Add, GeotechLocation.Edit, GeotechLocation.Import	Data Type:	String		

3.6.13.6 HydraulicPoint

Point feature representing a hydraulic calculation location, used to store calculated values. Created from RouteProfile.

Attribute:	# 3D1	Calculated:	Y	Domain:	N
Description:	3D chainage in metres.				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# 3Ddist	Calculated:	Y	Domain:	N
Description:	3D distance from the previous point in metres.				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# DesignHead	Calculated:	Y	Domain:	N
Description:	Design head in metres.				
Set by:	HydraulicPoint.Create	Data Type:	Real		



Attribute:	# FlowTemp	Calculated:	Y	Domain:	N
Description:	Flow temperature (°C).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# FrictionalPressureLoss	Calculated:	Y	Domain:	N
Description:	Frictional pressure loss (Pa).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# GroundTemp	Calculated:	Y	Domain:	N
Description:	Ground temperature (°C).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# HydraulicGradient	Calculated:	Y	Domain:	N
Description:	Hydraulic gradient in metres.				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# Point	Calculated:	Y	Domain:	N
Description:	Hydraulic point number.				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# PressureBarg	Calculated:	Y	Domain:	N
Description:	Calculated pressure (Barg).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# PressureDifferential	Calculated:	Y	Domain:	N
Description:	Pressure differential (Pa).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# PressurePa	Calculated:	Y	Domain:	N
Description:	Calculated pressure (Pa).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# ReynoldsNo	Calculated:	Y	Domain:	N
Description:	Reynolds number.				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# RouteEventID	Calculated:	Y	Domain:	N
Description:	RouteEventID of the CentreLine used to create the HydraulicPoint.				
Set by:	HydraulicPoint.Create	Data Type:	GUID		

Attribute:	# StaticPressureLoss	Calculated:	Y	Domain:	N
Description:	Static pressure loss (Pa).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# TempIn	Calculated:	Y	Domain:	N
Description:	Temperature in (°C).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# TempOut	Calculated:	Y	Domain:	N
Description:	Temperature out (°C).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

Attribute:	# Viscosity	Calculated:	Y	Domain:	N
Description:	Viscosity (cP).				
Set by:	HydraulicPoint.Create	Data Type:	Real		

3.6.13.7 IntersectionPoint

Point feature inserted on the intersection point of horizontal bends, based on CentreLine.

Attribute:	# Angle	Calculated:	Y	Domain:	N
Description:	Intersection point bend angle (direction specified in brackets).				
Set by:	IntersectionPoint.Create	Data Type:	String		

Attribute:	# RouteEventID	Calculated:	Y	Domain:	N
Description:	RouteEventID of the CentreLine that was used to create the route feature.				
Set by:	PIEERouteFeature.Create	Data Type:	GUID		

Attribute:	# Tag	Calculated:	Y	Domain:	N
Description:	Intersection point tag.				
Set by:	IntersectionPoint.Create	Data Type:	String		

3.6.13.8 Labels

Point feature representing a label location.

Attribute:	+ Value	Calculated:	N	Domain:	N
Description:	Label value.				
Set by:	Label.Add	Data Type:	String		



3.6.13.9 Notes

Point feature representing an engineering note location.

Attribute:	+ Note	Calculated:	N	Domain:	N
Description:	Engineering note text.				
Set by:	Note.Add	Data Type:	String		

3.6.13.10 Pipeline Markers

Point feature representing a pipeline marker location.

Attribute:	# Tag	Calculated:	Y	Domain:	N
Description:	Tag ID for the marker.				
Set by:	PipelineMarker.Add	Data Type:	String		

Attribute:	# Type	Calculated:	Y	Domain:	Y
Description:	Pipeline marker type.				
Set by:	PipelineMarker.Add	Data Type:	String		

3.6.13.11 StationPoint

Point feature representing a compression, pressure reduction or pumping station.

Attribute:	# Tag	Calculated:	Y	Domain:	Y
Description:	Station location tag.				
Set by:	StationPoint.Create	Data Type:	String		

Attribute:	# Power	Calculated:	Y	Domain:	N
Description:	Station power requirement (kW).				
Set by:	StationPoint.Create	Data Type:	Real		

Attribute:	# Type	Calculated:	Y	Domain:	Y
Description:	Station type (pump or compressor)				
Set by:	StationPoint.Create	Data Type:	String		



3.6.14 PEEPolygonFeatures

3.6.14.1 ConcreteCoating

Discrete feature defining a concrete coating range. There are no additional feature attributes.

Attribute:	# Description	Calculated:	Y	Domain:	N
Description:	Description of the concrete coating.				
Set by:	ConcreteCoating.Add, ConcreteCoating.Edit	Data Type:	String		

3.6.14.2 ConcreteSlab

Discrete feature defining a concrete slab pipeline protection range.

Attribute:	+ Thickness	Calculated:	N	Domain:	Y
Description:	Concrete thickness.				
Set by:	ConcreteSlab.Add, ConcreteSlab.Edit	Data Type:	Real		

3.6.14.3 Constraint

Discrete feature defining a construction constraint.

Attribute:	+ Constraint	Calculated:	N	Domain:	Y
Description:	Constraint type.				
Set by:	Constraint.Add, Constraint.Edit	Data Type:	String		

3.6.14.4 Cover

Continuous feature defining the depth of cover in metres to top of pipe.

Attribute:	+ Cover	Calculated:	Y	Domain:	N
Description:	Depth of cover in metres to top of pipe.				
Set by:	Cover.Add, Cover.Create, Cover.Delete, Cover.Edit, Cover.Merge	Data Type:	Real		

3.6.14.5 DOTSegment

Continuous feature created by the Class Location function.

Attribute:	# Code	Calculated:	Y	Domain:	Y
Description:	Design code.				
Set by:	ClassLocation.Create	Data Type:	String		



Attribute:	# Class	Calculated:	Y	Domain:	Y
Description:	Design class.				
Set by:	ClassLocation.Create	Data Type:	String		

Attribute:	# Dwellings	Calculated:	Y	Domain:	N
Description:	Number of dwellings (based on random mile with highest property count).				
Set by:	ClassLocation.Create	Data Type:	String		

Attribute:	# Reference	Calculated:	Y	Domain:	N
Description:	Reference.				
Set by:	ClassLocation.Create	Data Type:	String		

3.6.14.6 Hold

Discrete feature defining an engineering hold range.

Attribute:	# Hold	Calculated:	N	Domain:	N
Description:	Engineering hold.				
Set by:	Hold.Add, Hold.Edit	Data Type:	String		

3.6.14.7 ImageKey

Discrete feature defining an image key range.

Attribute:	+ ImageName	Calculated:	N	Domain:	N
Description:	Image filename.				
Set by:	ImageKey.Add, ImageKey.Edit	Data Type:	String		

Attribute:	+ ImageSeries	Calculated:	N	Domain:	N
Description:	Image series description.				
Set by:	ImageKey.Add, ImageKey.Edit	Data Type:	String		

3.6.14.8 PipeSegment

This is a continuous feature along the length of the pipeline defining the pipe or fitting type and material.

Attribute:	# Angle	Calculated:	Y	Domain:	N
Description:	Angle of the pipe segment, 0 if straight pipe.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	Real		



Attribute:	# DesignFactor	Calculated:	Y	Domain:	N
Description:	Design factor for the pipe segment.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	Real		

Attribute:	# Grade	Calculated:	Y	Domain:	Y
Description:	Material grade.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	String		

Attribute:	# ID	Calculated:	Y	Domain:	N
Description:	Pipe segment ID number.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	String		

Attribute:	# InsideDiameter	Calculated:	Y	Domain:	N
Description:	Inside diameter.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	Real		

Attribute:	# OutsideDiameter	Calculated:	Y	Domain:	Y
Description:	Outside diameter.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	Real		

Attribute:	# Radius	Calculated:	Y	Domain:	N
Description:	Pipe segment bend radius.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	Real		

Attribute:	# Tag	Calculated:	Y	Domain:	N
Description:	Tag ID for the pipe segment				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	String		



Attribute:	# Type	Calculated:	Y	Domain:	Y
Description:	Pipe segment type. (Ibend, Cbend, PIPE, Valve, IJ).				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	String		

Attribute:	# WallThickness	Calculated:	Y	Domain:	Y
Description:	Wall thickness of the pipe segment.				
Set by:	PipeSegment.Add, PipeSegment.Create, PipeSegment.Delete, PipeSegment.Edit, PipeSegment.Merge	Data Type:	String		

3.6.14.9 PipelineTemperatures

This is a continuous feature along the length of the pipeline defining the pipeline temperature in centigrade, rounded to the nearest 0.1 degree.

Attribute:	# Temperature	Calculated:	Y	Domain:	N
Description:	Temperature (in centigrade, rounded to the nearest 0.1 degree)				
Set by:	TemperatureContour.Import	Data Type:	Real		

Attribute:	# Type	Calculated:	Y	Domain:	Y
Description:	Temperature type, high or low				
Set by:	TemperatureContour.Import	Data Type:	Boolean		

3.6.14.10 Rainfall

Continuous feature defining rainfall data.

Attribute:	# KineticEnergy	Calculated:	Y	Domain:	N
Description:	Kinetic Energy I component of the Rainfall Erosivity Equation (MJ/ha.mm)				
Set by:	Rainfall.Create	Data Type:	Real		

Attribute:	# RainfallErosivity	Calculated:	Y	Domain:	N
Description:	Rainfall Erosivity I component of the Universal Soil Loss Equation (MJ.mm/ha.h)				
Set by:	Rainfall.Create	Data Type:	Real		

Attribute:	# MaxRainfallIntensity	Calculated:	Y	Domain:	N
Description:	Maximum Rainfall Intensity (I30) component of the Rainfall Erosivity Equation (mm/h)				
Set by:	Rainfall.Create	Data Type:	Real		



3.6.14.11 Reference

Discrete feature defining a reference drawing range.

Attribute:	+ Number	Calculated:	N	Domain:	N
Description:	Reference drawing number.				
Set by:	Reference.Add, Reference.Edit	Data Type:	String		

3.6.14.12 ReinstatementCode

Continuous feature defining the reinstatement code, created based on the SoilErosion feature. Allows for manual aggregation/simplification of the SoilErosion feature.

Attribute:	+ ReinstatementCode	Calculated:	Y	Domain:	Y
Description:	Reinstatement code, created base on the sttributes attached to the SoilErosion feature.				
Set by:	Reference.Add, Reference.Edit	Data Type:	String		

3.6.14.13 ROWWidth

Continuous feature defining the right of way width in metres.

Attribute:	+ Width	Calculated:	Y	Domain:	N
Description:	Right of way width in metres.				
Set by:	ROWWidth.Add, ROWWidth.Create, ROWWidth.Delete, ROWWidth.Edit, ROWWidth.Merge	Data Type:	Real		

3.6.14.14 SlopeAngle

Continuous feature defining the slope angle.

Attribute:	# SlopeAngle	Calculated:	Y	Domain:	N
Description:	Slope Angle in degrees (rounded to the nearest 0.1 degree).				
Set by:	SlopeAngle.Create	Data Type:	Real		

3.6.14.15 Soil

Continuous feature defining soil data.

Attribute:	# SoilErodability	Calculated:	Y	Domain:	N
Description:	Soil Erodability (K) component of the Universal Soil Loss Equation (h/MJ.mm)				
Set by:	Soil.Create	Data Type:	Real		

Attribute:	# SoilType	Calculated:	Y	Domain:	Y
Description:	Soil Type				
Set by:	Soil.Create	Data Type:	String		

3.6.14.16 SoilErosion

Continuous feature defining soil erosion data.

Attribute:	# AnnualSoilLoss	Calculated:	Y	Domain:	N
Description:	Annual Soil Loss (A) component of the Universal Soil Loss Equation (t/ha)				
Set by:	SoilErosion.Create	Data Type:	Real		

Attribute:	+ BermSpacing	Calculated:	Y	Domain:	Y
Description:	Berm spacing (m)				
Set by:	SoilErosion.Create	Data Type:	Real		

Attribute:	# CoverManagement	Calculated:	Y	Domain:	Y
Description:	Cover Management				
Set by:	SoilErosion.Create	Data Type:	String		

Attribute:	# ErosionClass	Calculated:	Y	Domain:	Y
Description:	Erosion Class I component of the Universal Soil Loss Equation				
Set by:	SoilErosion.Create	Data Type:	Integer		

Attribute:	# ErosionControlPractice	Calculated:	Y	Domain:	Y
Description:	Erosion Control Practice (P) component of the Universal Soil Loss Equation				
Set by:	SoilErosion.Create	Data Type:	String		

Attribute:	+ LandType	Calculated:	Y	Domain:	Y
Description:	Land Type				
Set by:	SoilErosion.Create	Data Type:	Integer		

Attribute:	+ Matting	Calculated:	Y	Domain:	Y
Description:	Flag to indicate that matting is required				
Set by:	SoilErosion.Create	Data Type:	Boolean		

Attribute:	# RainfallErosivity	Calculated:	Y	Domain:	N
Description:	Rainfall Erosivity I component of the Universal Soil Loss Equation (MJ.mm/ha.h)				
Set by:	SoilErosion.Create	Data Type:	Real		



Attribute:	+ SeedingType	Calculated:	Y	Domain:	Y
Description:	Seeding Type				
Set by:	SoilErosion.Create	Data Type:	String		

Attribute:	#SlopeAngle	Calculated:	Y	Domain:	N
Description:	Slope Angle in degrees (rounded to the nearest 0.1 degree).				
Set by:	SoilErosion.Create	Data Type:	Real		

Attribute:	# SlopeLength	Calculated:	Y	Domain:	N
Description:	Slope Length (m)				
Set by:	SoilErosion.Create	Data Type:	Real		

Attribute:	# SoilErodability	Calculated:	Y	Domain:	N
Description:	Soil Erodability (K) component of the Universal Soil Loss Equation (h/MJ.mm)				
Set by:	Soil.Create	Data Type:	Real		

3.6.14.17 Topography

Topographical feature i.e. road, railway, watercourse etc. Used to create CrossingPoints at the intersection of the StationLine and the Topography feature. Refer to Section 4.2 for topography codes.

Attribute:	+ CrossingMethod	Calculated:	Y	Domain:	Y
Description:	Topography crossing method code (see Section 4.1).				
Set by:	Topography.Add, Topography.Edit	Data Type:	String		

Attribute:	+ Description	Calculated:	Y	Domain:	Y
Description:	Topography description.				
Set by:	Topography.Add, Topography.Edit	Data Type:	String		

Attribute:	+ Elevation	Calculated:	Y	Domain:	N
Description:	Topography elevation or depth.				
Set by:	Topography.Add, Topography.Edit	Data Type:	Real		

Attribute:	+ Name	Calculated:	N	Domain:	N
Description:	Topography name.				
Set by:	Topography.Add, Topography.Edit	Data Type:	String		



Attribute:	+ SubType	Calculated:	Y	Domain:	Y
Description:	Topography sub type code (see Appendix 4.2).				
Set by:	Topography.Add, Topography.Edit	Data Type:	String		

Attribute:	+ Type	Calculated:	Y	Domain:	Y
Description:	Topography sub type code (see Appendix 4.2).				
Set by:	Topography.Add, Topography.Edit	Data Type:	String		

Attribute:	+ Width	Calculated:	Y	Domain:	N
Description:	Topography width in metres.				
Set by:	Topography.Add, Topography.Edit	Data Type:	Real		



3.7 Domain Lists

Domain Name	Values
PIEE.Locked	Yes, No
PIEE.Product	Gas, Oil
PIEEFeature.AbstractClass	Point, Polyline, Polygon
PIEEFeature.Automated	Yes, No
PIEEFeature.CheckChildLocation	Yes, No
PIEEMetadata.HistoricalState	Design, Construction, As-Built
PIEEMetadata.OperationalStatus	Active, Inactive
PIEEPolygon.Continuous	Yes, No
PIEESegment.Online	Yes, No
PIEEOfflineGeometry.GeometryType	Point, Polyline, Polygon
ForeignService.CrossingMethod	Refer to Section 4.1
ForeignService.Description	Refer to Section 4.1
ForeignService.SubType	Refer to Section 4.1
ForeignService.Type	Refer to Section 4.1
TemperatureContour.Type	High, Low
SoilContour.SoilType	List of project defined soil types
CentreLine.EditsAllowed	Yes, No
StationLine.Active	List of StationLines in PIEEModel
StationLine.Current	Yes, No
DOTSegment.Code	List of project defined design codes
DOTSegment.Class	List of project defined design classes
PipeSegment.Grade	List of project defined material grades
PipeSegment.OutsideDiameter	List of project defined outside diameters
PipeSegment.Type	List of project defined pipe segment types
PipeSegment.WallThickness	List of project defined wall thicknesses
ConcreteSlab.Thickness	List of project defined concrete thicknesses
Constraint.Constraint	List of project defined constraints
PipelineTemperature.Type	High, Low
Soil.SoilType	List of project defined soil types
SoilErosion.BermSpacing	List of project defined berm spacings
SoilErosion.CoverManagement	List of project defined cover management types
SoilErosion.ErosionClass	List of project defined erosion classes
SoilErosion.ErosionControlPractice	List of project defined erosion control practices
SoilErosion.LandType	List of project defined land types
SoilErosion.Matting	Yes, No



Domain Name	Values
SoilErosion.SeedingType	List of project defined seeding types
Topography.CrossingMethod	Refer to Section 4.2
Topography.Description	Refer to Section 4.2
Topography.SubType	Refer to Section 4.2
Topography.Type	Refer to Section 4.2
AerialMarker.Suppress	Yes, No
AerialMarker.Tag	List of project defined aerial marker tags
AerialMarker.Type	List of project defined aerial marker types
StationPoint.Tag	List of project defined station tags
StationPoint.Type	Compressor, Pump, Pressure Reduction
CPLocation.Tag	List of project defined cathodic protection location tags
CrossingPoint.AboveGround	Yes, No
GeotechLocation.Type	BH, CPT, TP
PipelineMarker.Type	P

3.8 Methods

The PIEE features are classified by type. Each feature lists the applicable methods with the scope of the method. The scope is either:

- ‘P’, the method is public and can be executed by the user.
- ‘I’, the method is internal and called from another function (code component).

The function code is used as a short name and is used on the use case flowcharts.

3.8.1 PIEEModel

Feature:	PIEEModel		Feature Type:	Model
Description:	Applies to the PIEE Model (drawing file). There is no associated geometry. All attributes are stored in dictionaries.			
Method	Scope	Description	Function Code	
Check	P	Checks the current PIEE model for referential integrity. The RouteEventID of the centreline is checked against all other RouteEventID attributes to determine which features need to be updated.	PIE-P-004-01	
Create	P	Creates a new PIEE model file from the existing file that is open in AutoCAD.	PIE-P-001-01	
Edit	P	Enables the user to set or edit the settings for the current PIEE model.	PIE-P-003-01	
Lock	P	Sets the flag indicating that changes are allowed to the CentreLine feature.	PIE-P-005-01	
Revise	P	Revises the current PIEE model.	PIE-P-002-01	

3.8.2 PIEESchedule

Feature:	PIEESchedule		Feature Type:	Model
Description:	Schedule definitions stored in a dictionary. There is no associated geometry.			
Method	Scope	Description	Function Code	
Create	P	Create a schedule based on an existing schedule definition. The schedule is exported to a .prn text file.	DES-P-002-01	
Define	P	Define a new schedule based on feature class attributes linked and sorted using the Primary Key Attribute. The schedule definition is stored in a dictionary.	DES-P-002-02	
Delete	P	Delete a schedule definition.	DES-P-002-03	
Edit	P	Edit a schedule definition.	DES-P-002-04	



3.8.3 PIEEMetadata

Feature:	Multiple	Feature Type:	Multiple
Description:	Applies to all PIEE Features.		
Method	Scope	Description	Function Code
EditMetadata	P	Updates the chainage and positional information for the feature	FEA-P-008-01

3.8.4 PIEEFeature

Feature:	Multiple	Feature Type:	Multiple
Description:	Applies to all PIEE Features.		
Method	Scope	Description	Function Code
Add	P	Add a single instance of a feature	FEA-P-001-01
Check	P	Check feature data.	FEA-P-002-01
Create	P	Create instances of a feature automatically	FEA-P-003-01
Define	P	Define a new feature class.	FEA-P-004-01
Delete	P	Remove a feature class.	FEA-P-005-01
Define	P	Define a new feature class.	FEA-P-005-01
Display	P	Display feature class attributes.	FEA-P-006-01
Edit	P	Edit feature class user editable attributes.	FEA-P-007-01
EditMetadata	P	Edit feature class user editable metadata.	FEA-P-008-01
Export	P	Export feature class to an external file.	FEA-P-009-01
Find	P	Find feature in the model.	FEA-P-010-01
Import	P	Import feature class from an external file.	FEA-P-011-01
Link	P	Link parent and child entities.	FEA-P-012-01
Merge	P	Merge selected features.	FEA-P-013-01
RemoveData	P	Remove feature class data from an AutoCAD entity.	FEA-P-014-01
Set	P	Prompt to select an AutoCAD entity to set as a feature.	FEA-P-015-01
Unlink	P	Unlink parent and child entities.	FEA-P-016-01
Update	P	Update feature chainage and positional information.	FEA-P-015-01



3.8.5 PIEEOfflineFeatures

Feature:	PIEEOfflineFeature		Feature Type:	PIEEOfflineFeature
Description:	Offline features.			
Method	Scope	Description	Function Code	
Add	P	Add offline feature class data.	FEA-P-022-01	
Edit	P	Edit offline feature class data.	FEA-P-022-02	
RemoveData	P	Remove offline feature class data	FEA-P-022-02	

3.8.6 PIEERouteFeatures

Feature:	CentreLine		Feature Type:	Route
Description:	Route related polyline geometry with attributes. Defines the 2D centre line for the route with no bends (IPs only).			
Method	Scope	Description	Function Code	
Set	P	Prompts the user to select a polyline which will define the 2D centreline for the route.	ROU-P-001-01	
Check	I	Check that CentreLine has been set, and check all route feature RouteEventID's against CentreLine RouteEventID.	ROU-I-001-02	

Feature:	StationLine		Feature Type:	Route
Description:	Route stationing polyline geometry with attributes. Defines the 2D stationing line for the route with bends. Used to calculate chainage.			
Method	Scope	Description	Function Code	
Create	P	Creates a new StationLine based on the route CentreLine.	ROU-P-003-01	
Set	P	Prompts the user to select a polyline which will be set as the active StationLine.	ROU-P-003-02	
Check	I	Check that StationLine exists, StationLine RouteEventID matches CentreLine RouteEventID and PIEEModel edit flag is set to NIL.	ROU-I-003-03	

Feature:	GroundProfile		Feature Type:	Route
Description:	Ground profile 3D polyline geometry, based on the route StationLine and Contours or elevation data.			
Method	Scope	Description	Function Code	
Create	P	Creates a new GroundProfile based on the route StationLine and contours or elevation data.	ROU-P-004-01	
Import	I	Imports GroundProfile from a .prn file	ROU-I-004-02	
Check	I	Check that GroundProfile exists, GroundProfile RouteEventID matches CentreLine RouteEventID and PIEEModel edit flag is set to NIL.	ROU-I-004-03	



Feature:	RouteProfile		Feature Type:	Route
Description:	Route profile 3D polyline geometry, based on the route StationLine.			
Method	Scope	Description	Function Code	
Create	P	Creates a new RouteProfile based on the StationLine.	ROU-P-005-01	
Import	I	Imports RouteProfile from a .prn file	ROU-I-005-02	
Check	I	Check that RouteProfile exists, RouteProfile RouteEventID matches CentreLine RouteEventID and PIEEModel edit flag is set to NIL.	ROU-I-005-03	

Feature:	HydraulicProfile		Feature Type:	Route
Description:	Simplified route profile 3D polyline geometry, based on the RouteProfile.			
Method	Scope	Description	Function Code	
Create	P	Creates a new HydraulicProfile based on the RouteProfile.	ROU-P-006-01	

Feature:	ReinstatementProfile		Feature Type:	Route
Description:	Simplified ground profile 3D polyline geometry, based on the GroundProfile.			
Method	Scope	Description	Function Code	
Create	P	Creates a new ReinstatementProfile based on the GroundProfile.	ROU-P-007-01	
Check	I	Check that ReinstatementProfile exists, ReinstatementProfile RouteEventID matches CentreLine RouteEventID and PIEEModel edit flag is set to NIL.	ROU-I-007-02	

3.8.7 PIEEPolylineFeatures

Feature:	Contour		Feature Type:	Polyline
Description:	Polyline features representing the elevation model (topography).			
Method	Scope	Description	Function Code	
Create	P	Set contours to correct elevation & remove #Z1 attribute to xdata	TOP-P-003-01	
Import	I	Prompt user to select contours, flatten contours and add #Z1 attribute to xdata	TOP-P-004-01	

Feature:	ForeignService		Feature Type:	Polyline
Description:	Foreign service feature i.e. pipeline, cable			
Method	Scope	Description	Function Code	
Add	P	Add ForeignService feature class data to selected polyline.	FEA-P-021-01	
Edit	P	Edit ForeignService feature class data.	FEA-P-021-02	
RemoveData	P	Remove Foreign Service feature class data from polyline.	FEA-P-021-03	



Feature:	RainfallContour	Feature Type:	Polyline
Description:	Polyline features representing rainfall.		
Method	Scope	Description	Function Code
Import	I	Import rainfall contours, add #RainfallErosivity attribute.	ENV-P-002-01

Feature:	SoilContour	Feature Type:	Polyline
Description:	Polyline features representing soil types.		
Method	Scope	Description	Function Code
Import	I	Import soil contours, add #SoilErodability and #SoilType attributes.	ENV-P-003-02

Feature:	TemperatureContour	Feature Type:	Polyline
Description:	Polyline features representing the elevation model (topography).		
Method	Scope	Description	Function Code
Import	I	Import high/low temperature contours, add #Temperature, #Type and #Z1 attributes.	TOP-P-004-01

3.8.8 PIEEPntFeatures

Feature:	AerialMarker	Feature Type:	Point
Description:	Point feature representing an Aerial Marker.		
Method	Scope	Description	Function Code
Create	P	Create aerial markers based on StationLine.	ENG-P-003-01
Edit	P	Edit aerial marker feature class data.	ENG-P-003-02

Feature:	Building	Feature Type:	Point
Description:	Point feature representing a building.		
Method	Scope	Description	Function Code
Add	P	Add building location.	ENG-P-017-01
Edit	P	Edit building feature class data.	ENG-P-017-02
Import	P	Import building locations from a .prn file	ENG-P-017-03

Feature:	StationPoint	Feature Type:	Point
Description:	Point feature representing a compression, pumping or pressure reduction station.		
Method	Scope	Description	Function Code
Create	P	Insert station points based on RouteProfile.	ENG-P-023-01



Feature:	CPLocation		Feature Type:	Point
Description:	Point feature representing a pipeline cathodic protection location.			
Method	Scope	Description	Function Code	
Add	P	Add cathodic protection location.	ENG-P-018-01	
Edit	P	Edit cathodic protection location feature class data.	ENG-P-018-02	
Import	P	Import cathodic protection locations from a .prn file	ENG-P-018-03	

Feature:	CrossingPoint		Feature Type:	Point
Description:	Crossing point location, inserted on the intersection of the StationLine and ForeignService or Topography feature.			
Method	Scope	Description	Function Code	
Create	I	Insert crossing points on the intersection of the StationLine and ForeignService or Topography feature.	ENG-I-001-02	

Feature:	GeotechLocation		Feature Type:	Point
Description:	Point feature representing a geotechnical sample location.			
Method	Scope	Description	Function Code	
Add	P	Add geotechnical sample location.	ENG-P-019-01	
Edit	P	Edit geotechnical sample location feature class data.	ENG-P-019-02	
Import	P	Import geotechnical sample locations from a .prn file	ENG-P-019-03	

Feature:	HydraulicPoint		Feature Type:	Point
Description:	Point feature representing a hydraulic calculation location, used to store calculated values.			
Method	Scope	Description	Function Code	
Create	P	Insert hydraulic points based on RouteProfile.	ENG-I-001-02	

Feature:	IntersectionPoint		Feature Type:	Point
Description:	Point feature inserted on the intersection point of horizontal bends, based on CentreLine.			
Method	Scope	Description	Function Code	
Create	P	Insert intersection points on CentreLine horizontal bend intersection points.	ROU-P-002-01	
Check	I	Check that intersection points exist and intersection point RouteEventID's match CentreLine RouteEventID.	ROU-I-002-01	



Feature:	Label	Feature Type:	Point
Description:	Point feature representing a label location.		
Method	Scope	Description	Function Code
Add	P	Add label location.	ENG-P-020-01
Edit	P	Edit label feature class data.	ENG-P-020-02
Import	P	Import label locations from a .prn file	ENG-P-020-03
Link	P	Link label point feature to an entity	ENG-P-020-04
Unlink	P	Unlink label point feature from an entity	ENG-P-020-05

Feature:	Note	Feature Type:	Point
Description:	Point feature representing an engineering note location.		
Method	Scope	Description	Function Code
Add	P	Add note location.	ENG-P-021-01
Edit	P	Edit note feature class data.	ENG-P-021-02
Import	P	Import note locations from a .prn file	ENG-P-021-03

3.8.9 PEEEPolygonFeatures

Feature:	ConcreteCoating	Feature Type:	Polygon
Description:	Discrete feature defining range of concrete coating.		
Method	Scope	Description	Function Code
Add	P	Add a concrete coating range based on StationLine KP range or picked points.	ENG-P-010-01
Edit	P	Edit concrete coating attributes and range.	ENG-P-010-02

Feature:	ConcreteSlab	Feature Type:	Polygon
Description:	Discrete feature defining range of concrete slab pipeline protection.		
Method	Scope	Description	Function Code
Add	P	Add a concrete slab range based on StationLine KP range or picked points.	ENG-P-011-01
Edit	P	Edit concrete slab attributes and range.	ENG-P-011-02

Feature:	Constraint	Feature Type:	Polygon
Description:	Discrete feature defining range of construction constraint.		
Method	Scope	Description	Function Code
Add	P	Add a constraint range based on StationLine KP range or picked points.	ENG-P-012-01
Edit	P	Edit constraint attributes and range.	ENG-P-012-02



Feature:	Cover	Feature Type:	Polygon
Description:	Continuous feature defining the depth of cover in metres to top of pipe.		
Method	Scope	Description	Function Code
Add	P	Add a cover range based on StationLine KP range or picked points.	ENG-P-013-01
Create	P	Create covers automatically based on StationLine.	ENG-P-013-02
Delete	P	Delete a cover range	ENG-P-013-03
Edit	P	Edit cover attributes and range.	ENG-P-013-04
Merge	P	Merge cover ranges.	ENG-P-013-05

Feature:	DOTSegment	Feature Type:	Polygon
Description:	Used for class location calculation.		
Method	Scope	Description	Function Code
Create	I	Creates DOTSegment polygon feature, used for class location calculation.	ENG-I-004-03

Feature:	Hold	Feature Type:	Polygon
Description:	Discrete feature defining an engineering hold range.		
Method	Scope	Description	Function Code
Add	P	Adds an engineering hold range based on StationLine KP range or picked points.	ENG-P-014-01
Edit	P	Edit engineering hold attributes and range.	ENG-P-014-02

Feature:	ImageKey	Feature Type:	Polygon
Description:	Discrete feature defining an image key range.		
Method	Scope	Description	Function Code
Add	P	Adds an image key range based on StationLine KP range or picked points.	TOP-P-005-01
Edit	P	Edit image key attributes and range.	TOP-P-005-02

Feature:	PipeSegment	Feature Type:	Polygon
Description:	Continuous feature along the length of the pipeline defining the pipe or fitting type and material.		
Method	Scope	Description	Function Code
Add	P	Add a section to the PipeSegment feature.	ENG-P-009-01
Create	P	Creates PipeSegment polygon feature from StationLine.	ENG-P-009-02
Delete	P	Deletes a section from the PipeSegment feature.	ENG-P-009-03
Edit	P	Edits a section of the PipeSegment feature.	ENG-P-009-04
Merge	P	Merge PipeSegment sections	ENG-P-009-05



Feature:	PipelineTemperature	Feature Type:	Polygon
Description:	Continuous feature along the length of the pipeline defining the pipeline temperature.		
Method	Scope	Description	Function Code
Create	P	Creates PipelineTemperature polygon feature from StationLine and TemperatureContours.	ENG-P-007-02

Feature:	Rainfall	Feature Type:	Polygon
Description:	Continuous feature defining the soil type.		
Method	Scope	Description	Function Code
Create	I	Create rainfall polygons based on ReinstatementProfile, SlopeAngles and RainfallContours.	ENV-I-002-01

Feature:	Reference	Feature Type:	Polygon
Description:	Discrete feature defining a reference drawing range.		
Method	Scope	Description	Function Code
Add	P	Adds a reference drawing range based on StationLine KP range or picked points.	ENG-P-015-01
Edit	P	Edit reference drawing attributes and range.	ENG-P-015-02

Feature:	ReinstatementCode	Feature Type:	Polygon
Description:	Continuous feature defining the reinstatement code, created based on the SoilErosion feature.		
Method	Scope	Description	Function Code
Add	P	Add a reinstatement code range based on StationLine KP range or picked points.	ENV-P-001-01
Create	P	Create reinstatement codes based on the SoilErosion feature.	ENV-P-001-02
Delete	P	Delete reinstatement code range.	ENV-P-001-03
Edit	P	Edit reinstatement code attribute and range	ENV-P-001-04
Merge	P	Merge reinstatement code ranges	ENV-P-001-05

Feature:	ROWWidth	Feature Type:	Polygon
Description:	Continuous feature defining the right of way width in metres.		
Method	Scope	Description	Function Code
Add	P	Add ROW width range based on StationLine KP range or picked points.	ENG-P-016-01
Create	P	Create ROW width ranges automatically based on StationLine.	ENG-P-016-02
Delete	P	Delete ROW width range	ENG-P-016-03
Edit	P	Edit ROW width attributes and range.	ENG-P-016-04
Merge	P	Merge ROW width ranges.	ENG-P-016-05



Feature:	SlopeAngle		Feature Type:	Polygon
Description:	Continuous feature defining the slope angle in degrees (rounded to the nearest 0.1 degree).			
Method	Scope	Description	Function Code	
Create	P	Create slope angles based on ReinstatementProfile..	TOP-P-001-01	

Feature:	Soil		Feature Type:	Polygon
Description:	Continuous feature defining the soil type.			
Method	Scope	Description	Function Code	
Create	I	Create soil polygons based on ReinstatementProfile, SlopeAngles and SoilContours.	ENV-I-003-01	

Feature:	SoilErosion		Feature Type:	Polygon
Description:	Continuous feature defining soil erosion.			
Method	Scope	Description	Function Code	
Create	I	Create soil erosion polygons based on ReinstatementProfile, SlopeAngles, RainfallCountours and SoilContours.	ENV-P-003-03	

Feature:	Topography		Feature Type:	Polygon
Description:	Topographical feature i.e. road, railway, river etc.			
Method	Scope	Description	Function Code	
Add	P	Add feature class data to topographical feature.	TOP-P-006-01	
Edit	P	Edit topographical feature class data.	TOP-P-006-02	
RemoveData	P	Remove topographical feature class data.	TOP-P-006-03	

3.9 Function Flowcharts

The function flowcharts are based on the activity diagram format (Wiegers and Beatty, 2013: 154). Irrespective of the feature class that the method applies to, they have been grouped according to function. The functional group is identified by the first three characters of the function code.

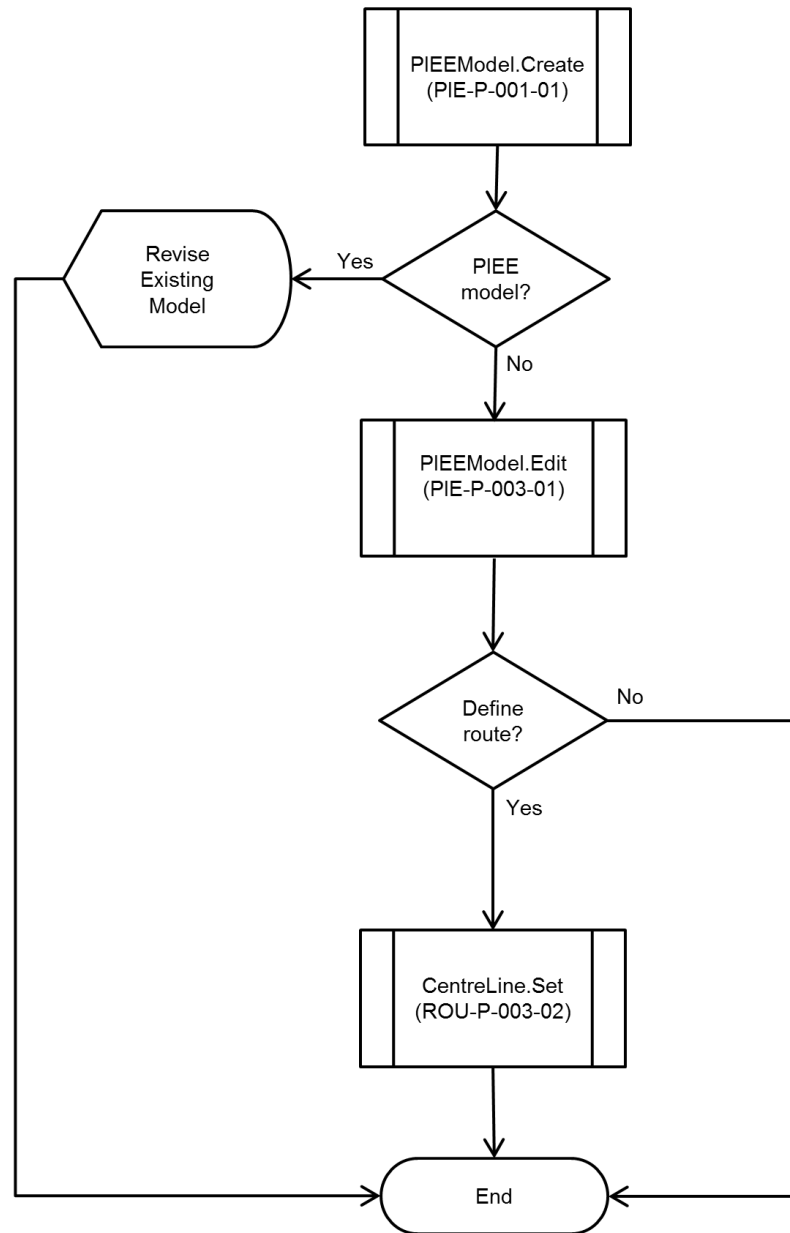
Function Code Prefix	Function Grouping
MOD	Model
ROU	Route
ENG	Engineering
TOP	Topography
FEA	Feature
DAT	Data
DES	Design



3.9.1 Model Functions (MOD)

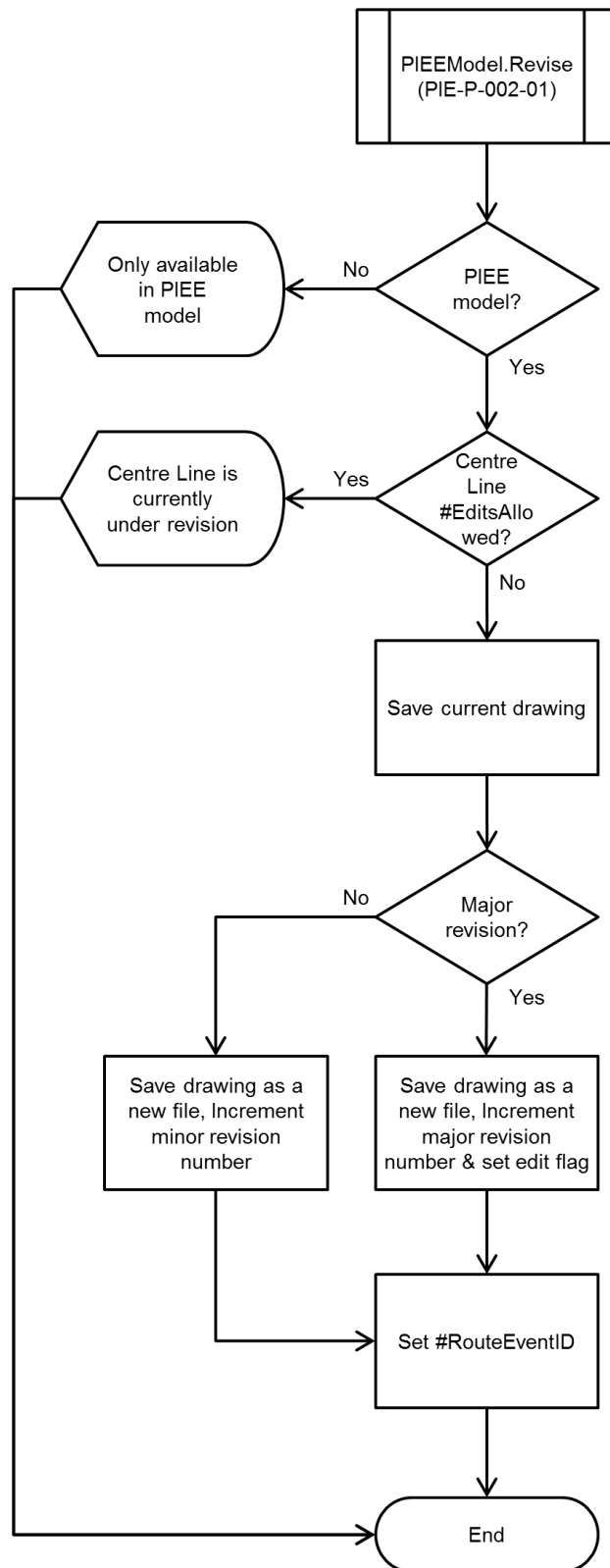


3.9.1.1 *PIEEModel.Create (PIE-P-001-01)*



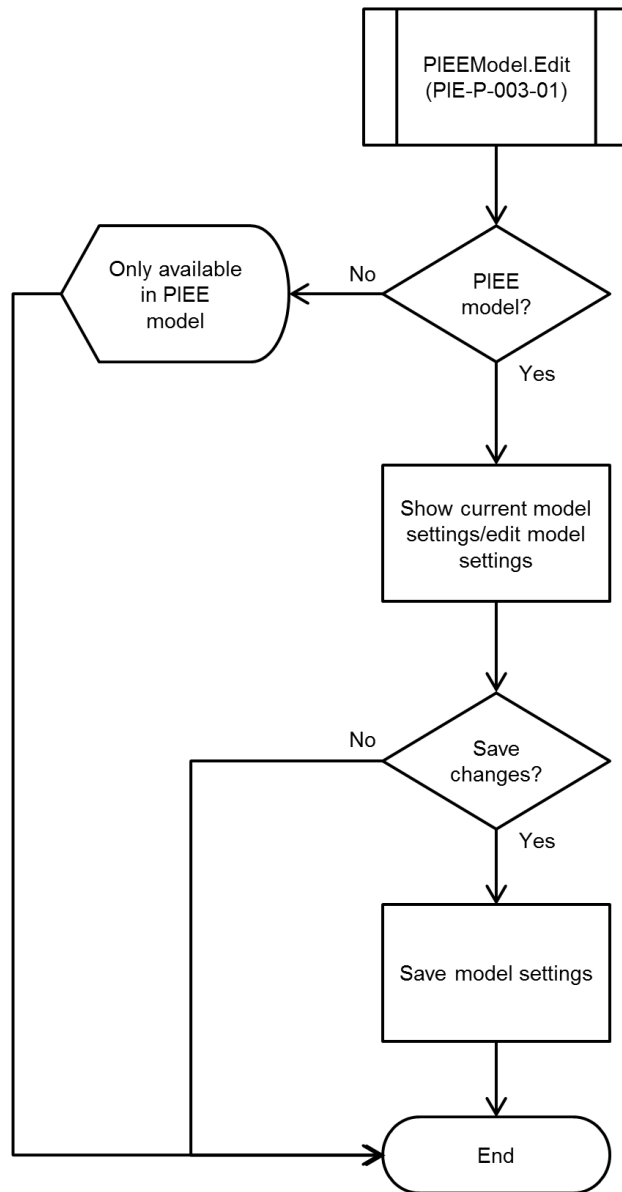


3.9.1.2 *PIEEModel.Revise (PIE-P-002-01)*



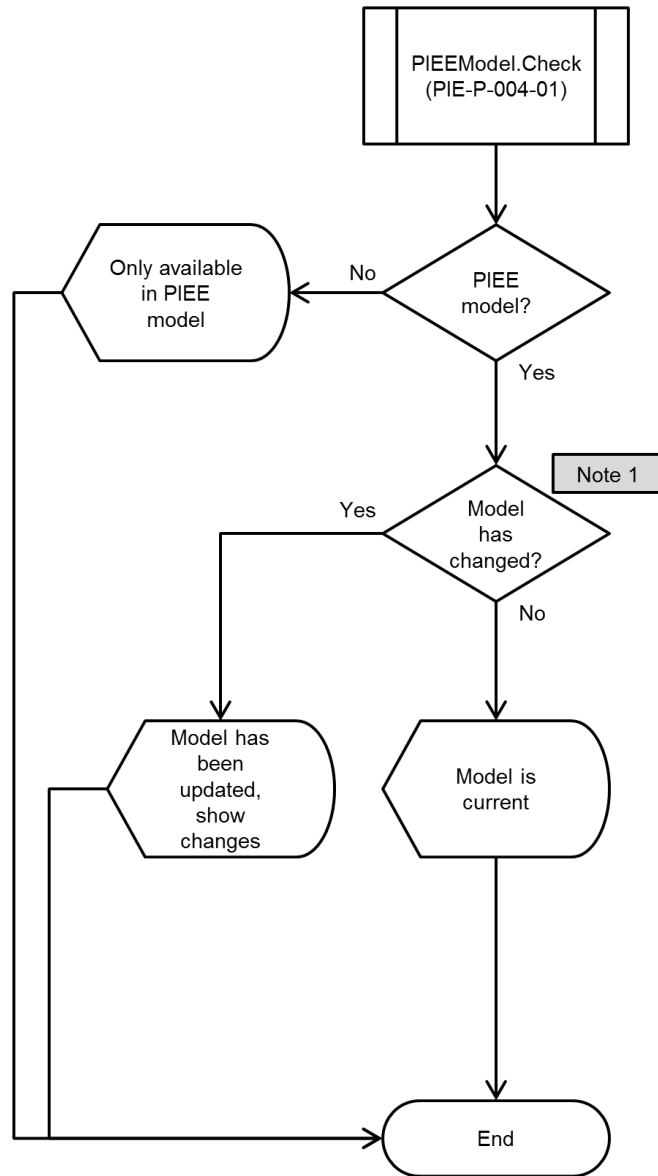


3.9.1.3 *PIEModel.Edit* (PIE-P-003-01)



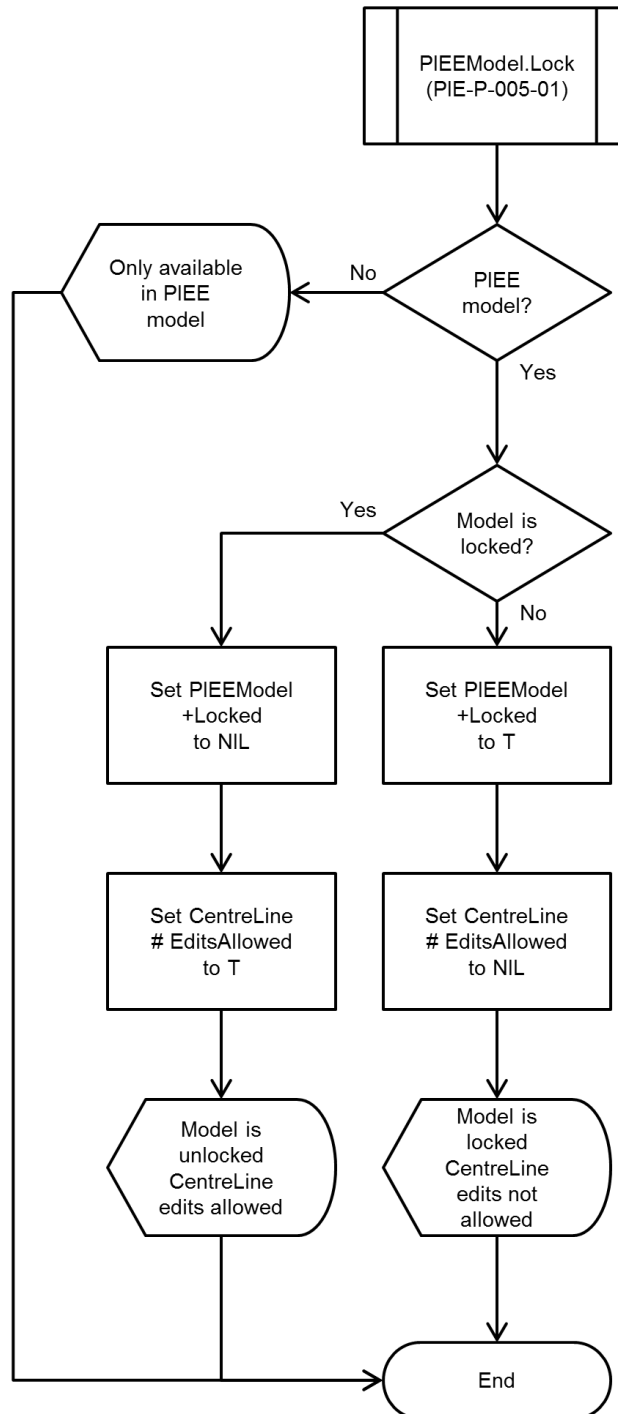


3.9.1.4 *PIEEModel.Check (PIE-P-004-01)*





3.9.1.5 *PIEEModel.Lock (PIE-P-005-01)*

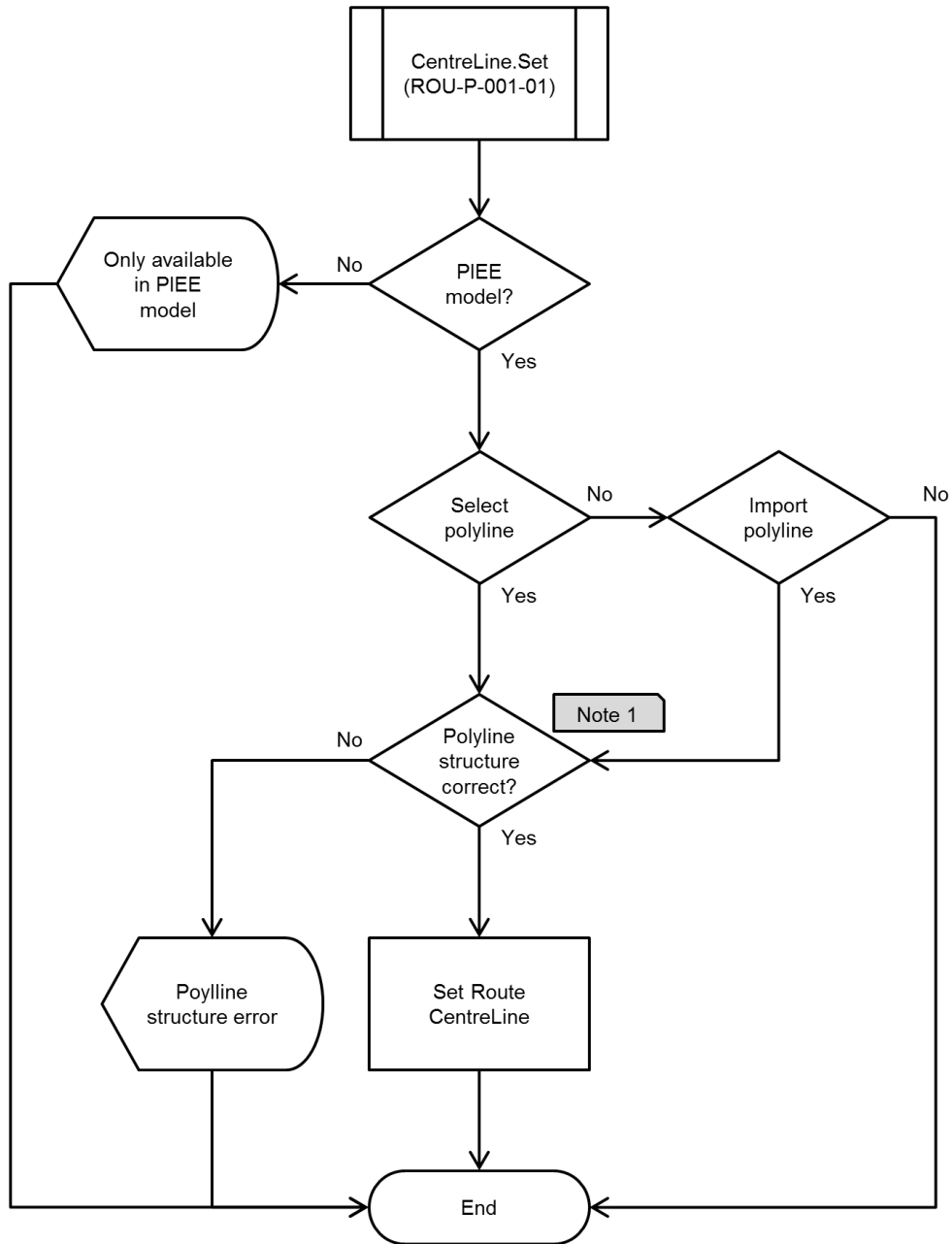




3.9.2 Route Functions (ROU)



3.9.2.1 CentreLine.Set (ROU-P-001-01)

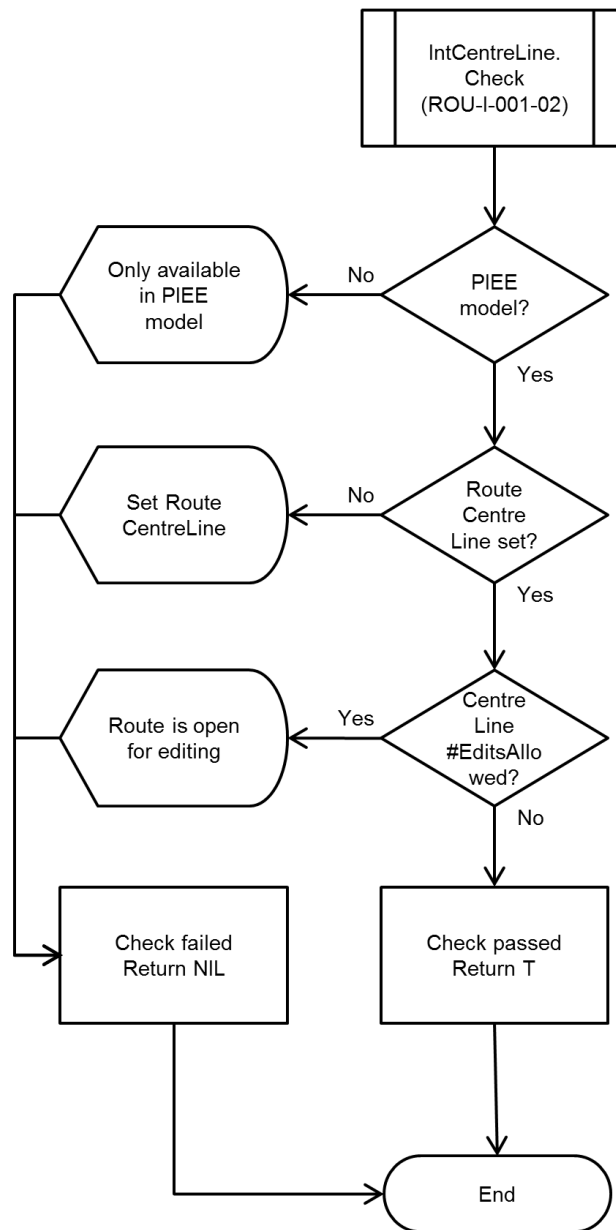


Notes

1. Function should check for zero length sections, polyline reversal etc and could include a fuzz factor for bends.

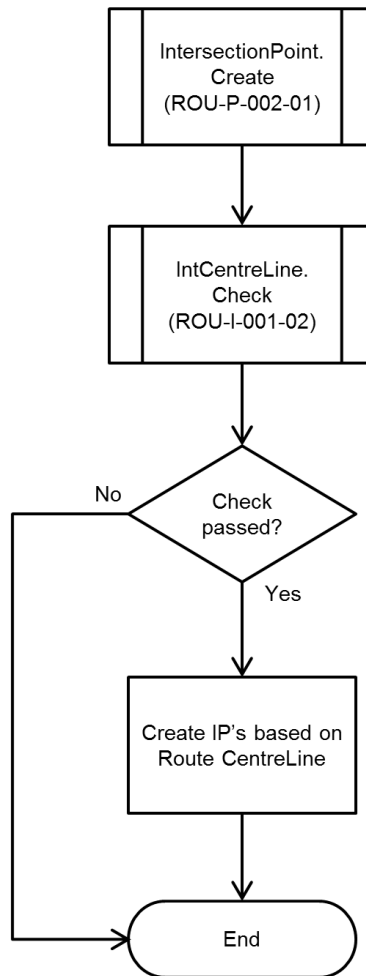


3.9.2.2 IntCentreLine.Check (ROU-I-001-02)



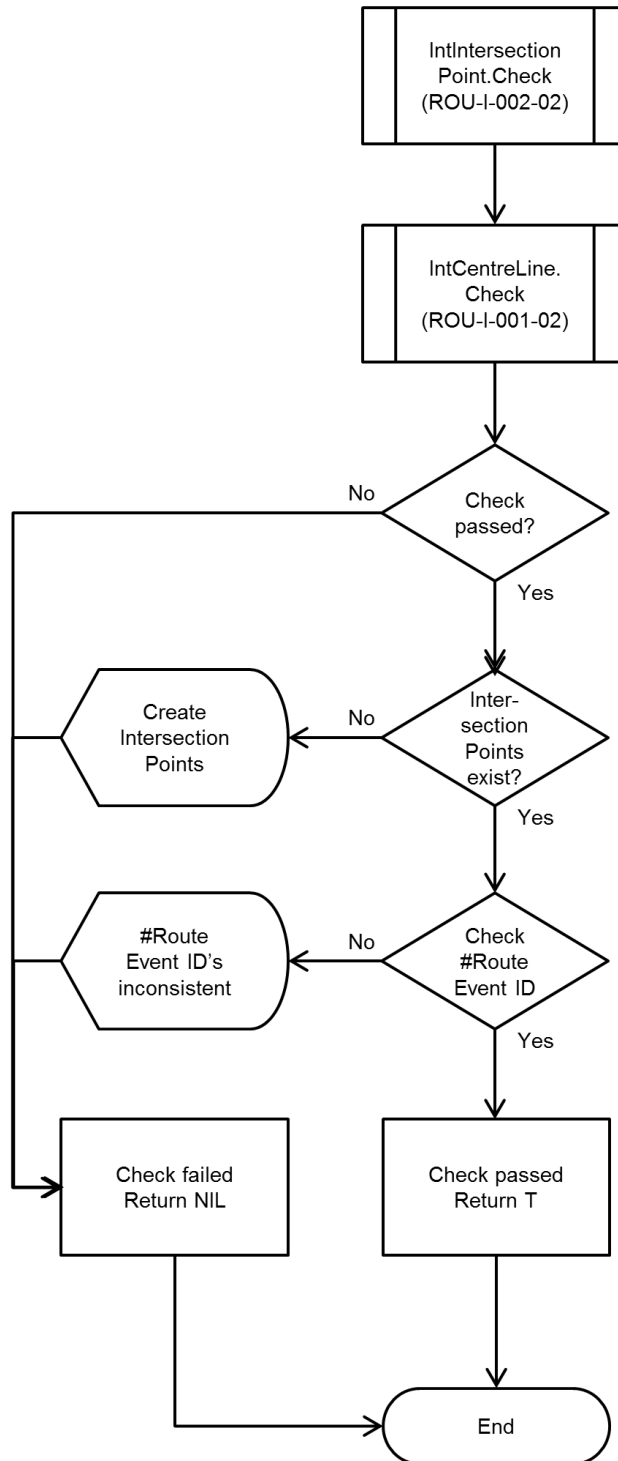


3.9.2.3 IntersectionPoint.Create (ROU-P-002-01)



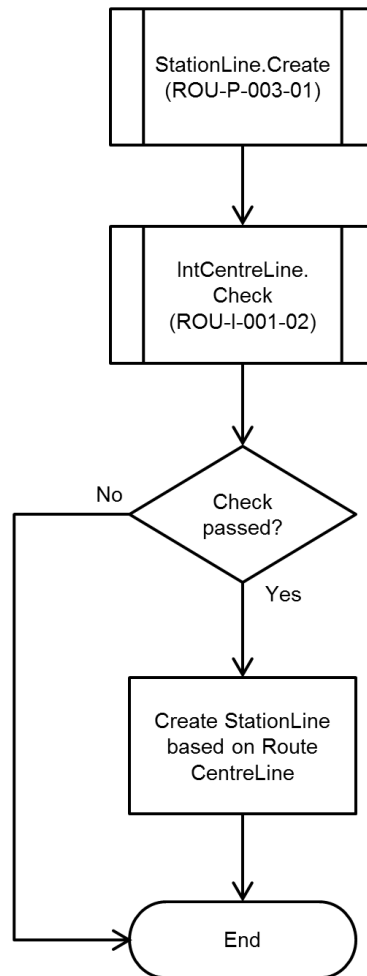


3.9.2.4 IntersectionPoint.Check (ROU-I-002-02)



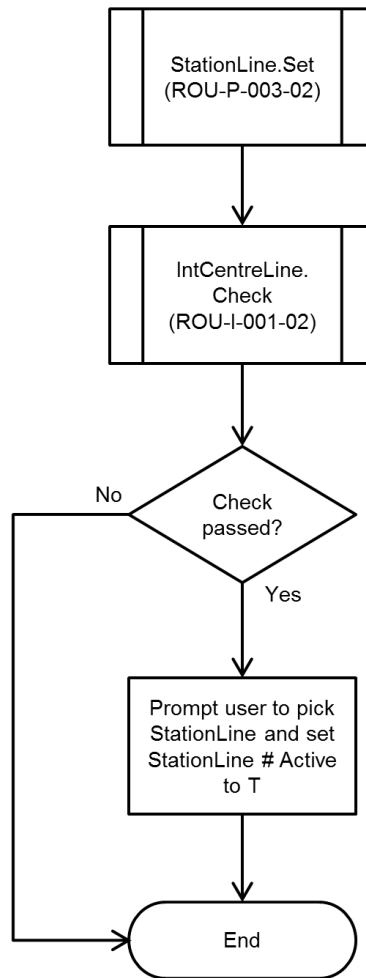


3.9.2.5 StationLine.Create (ROU-P-003-01)



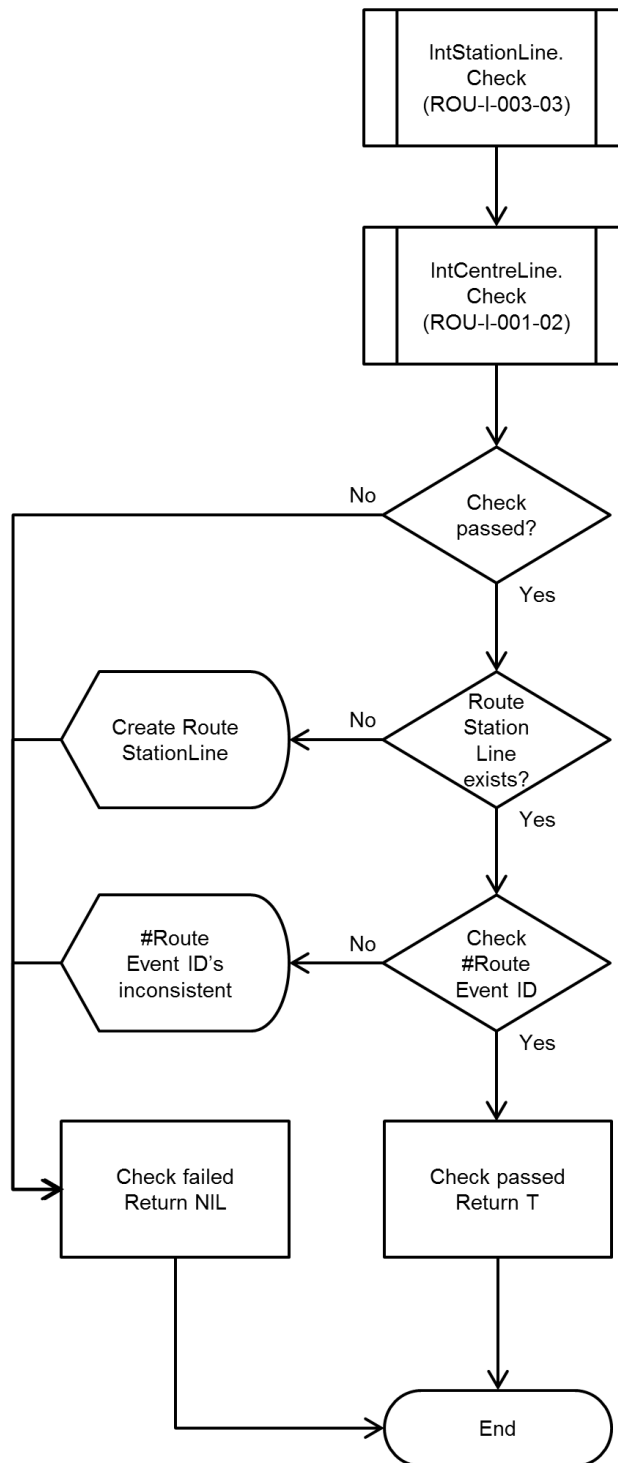


3.9.2.6 StationLine.Set (ROU-P-003-02)



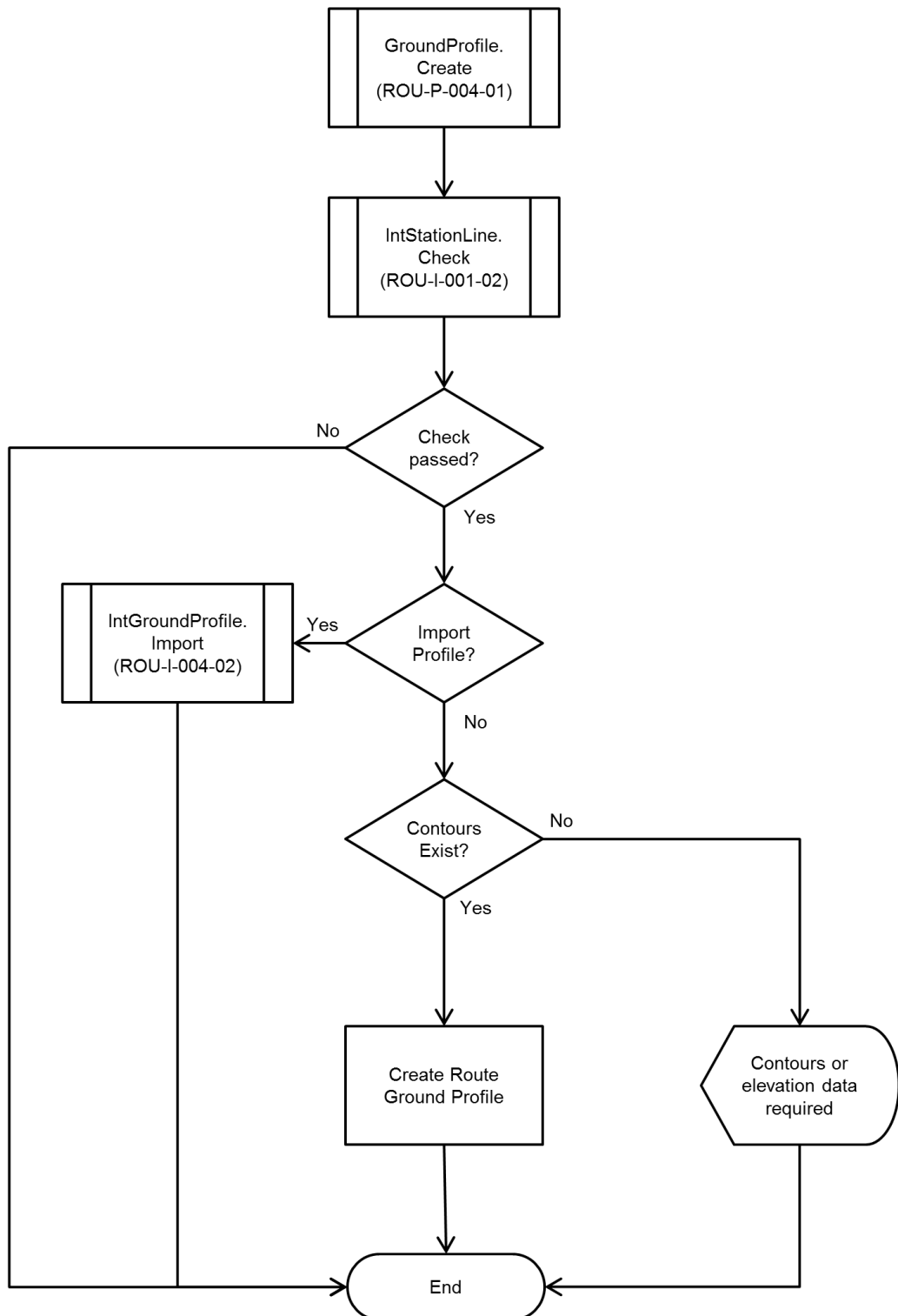


3.9.2.7 IntStationLine.Check (ROU-I-003-03)



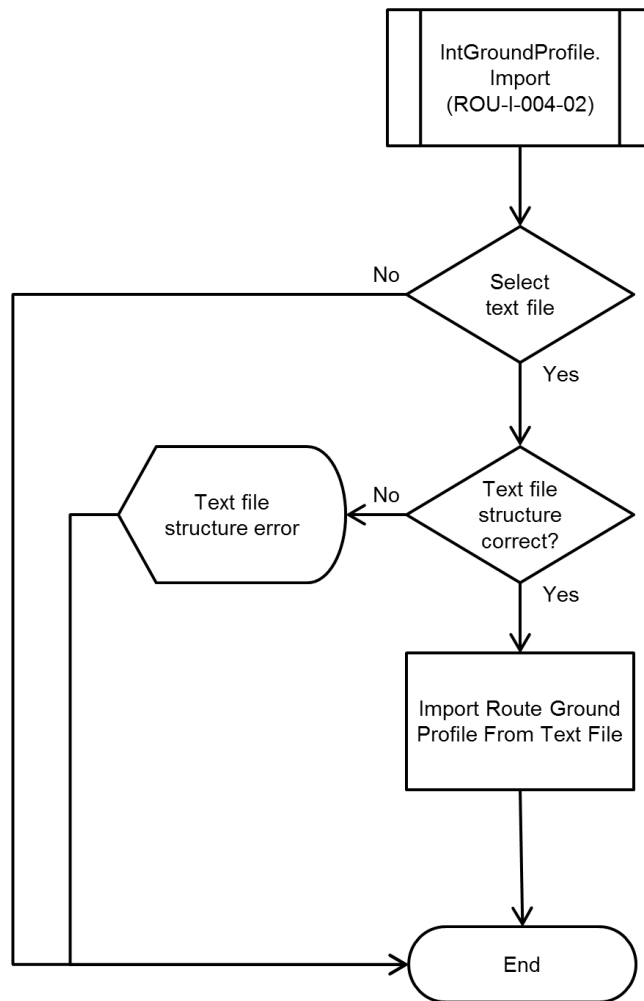


3.9.2.8 *GroundProfile.Create (ROU-P-004-01)*



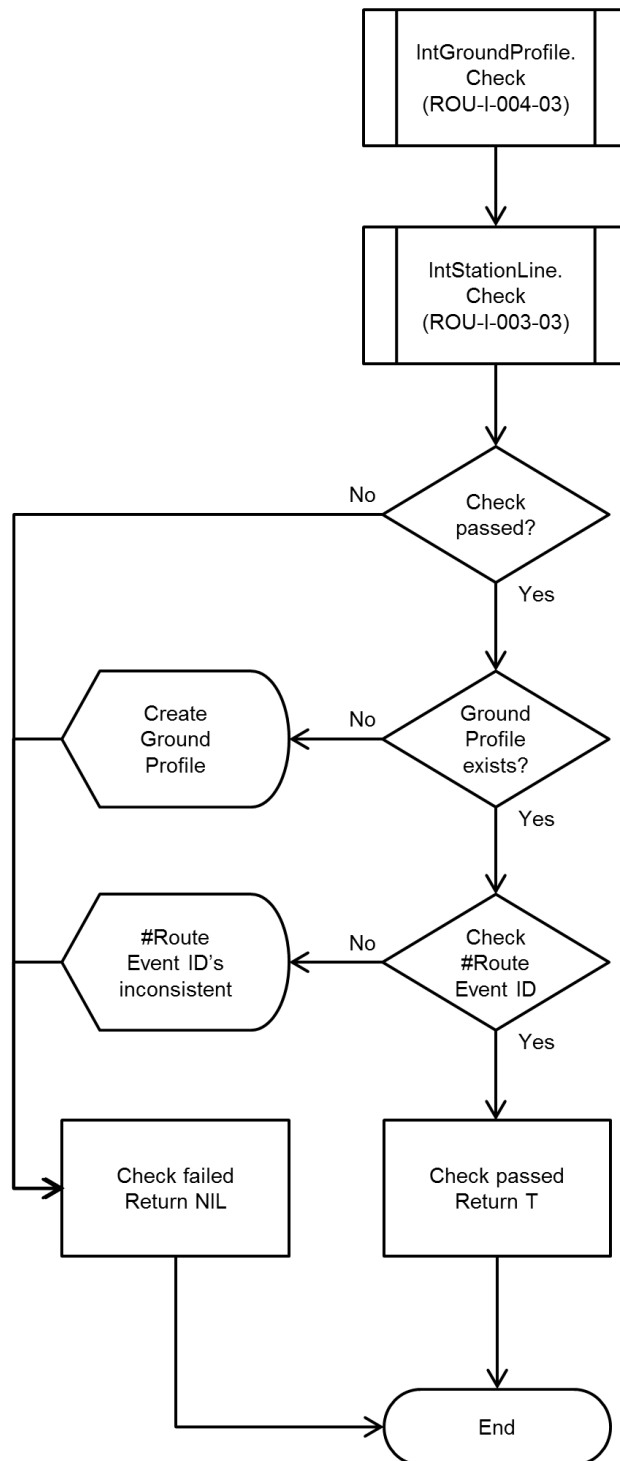


3.9.2.9 IntGroundProfile.Import (ROU-I-004-02)



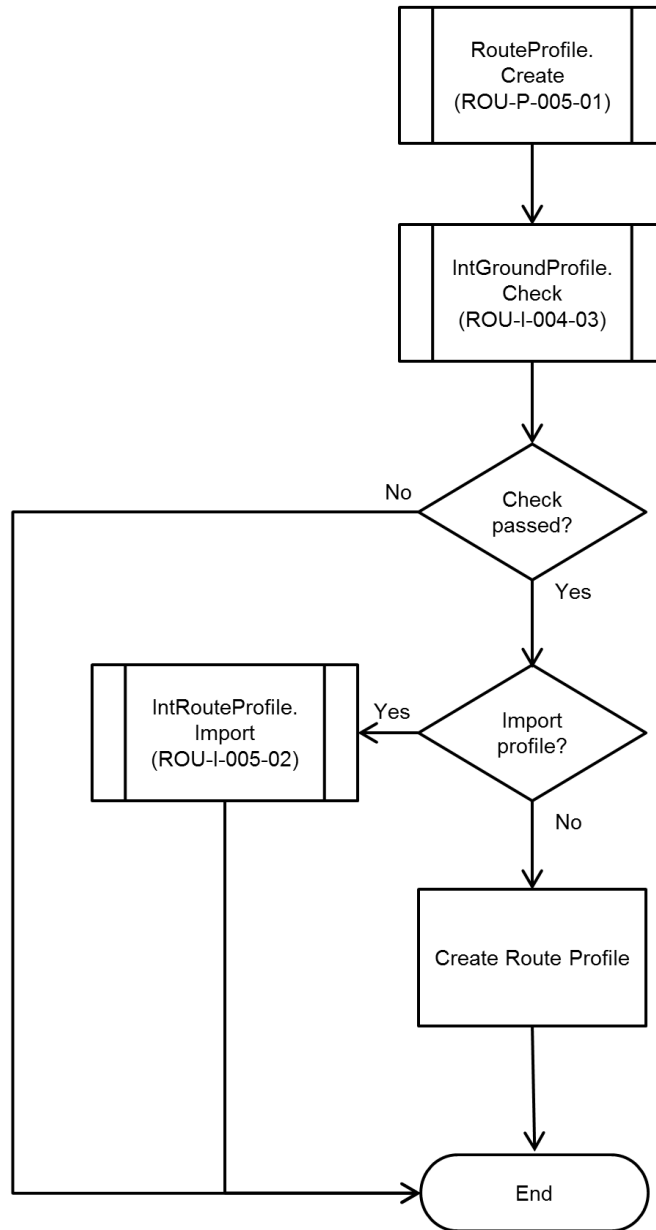


3.9.2.10 IntGroundProfile.Check (ROU-I-004-03)



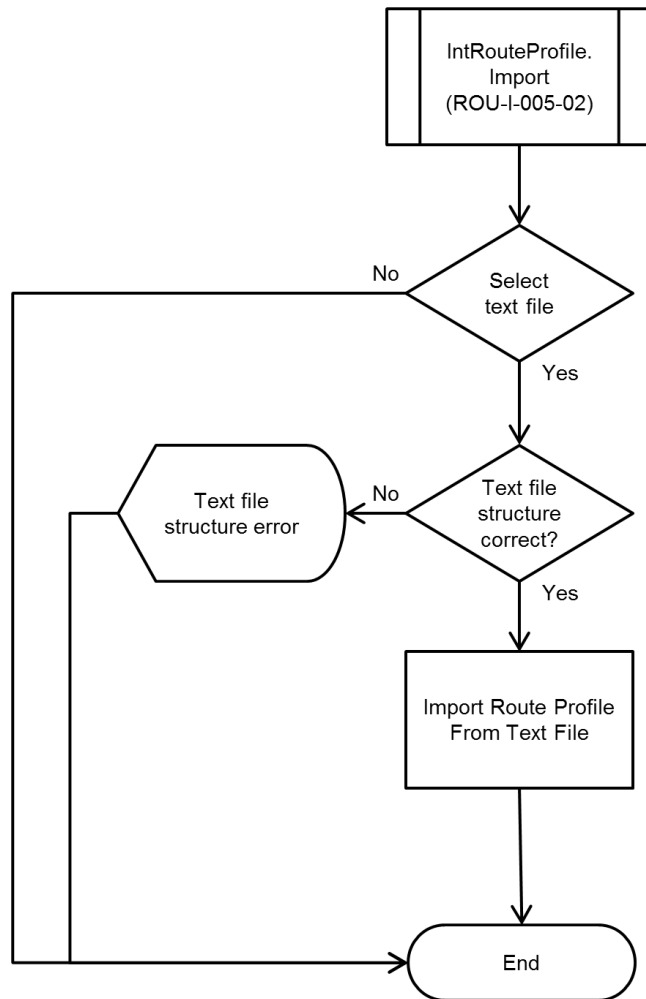


3.9.2.11 RouteProfile.Create (ROU-P-005-01)



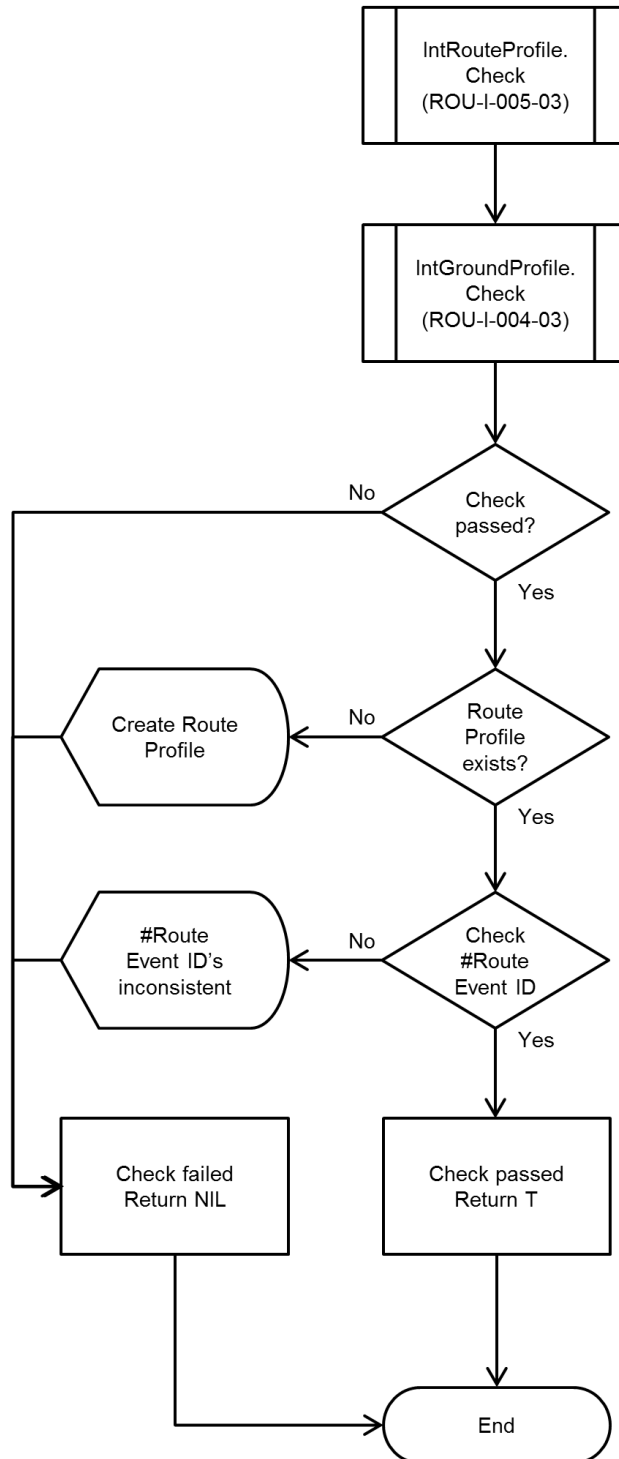


3.9.2.12 *IntRouteProfile.Import* (ROU-I-005-02)



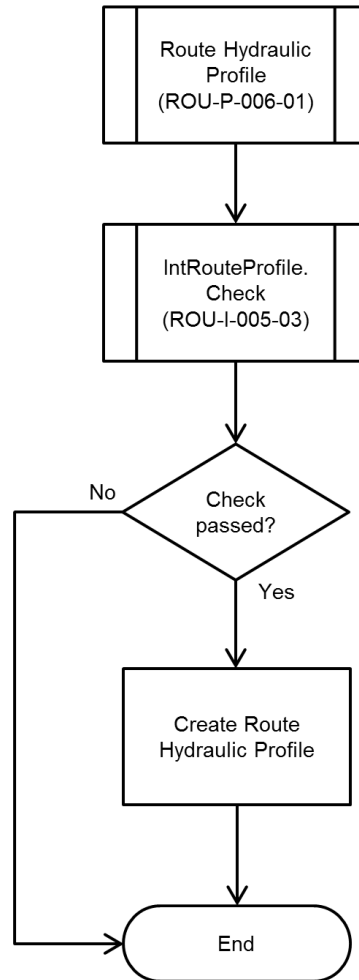


3.9.2.13 *IntRouteProfile.Check* (ROU-I-005-03)



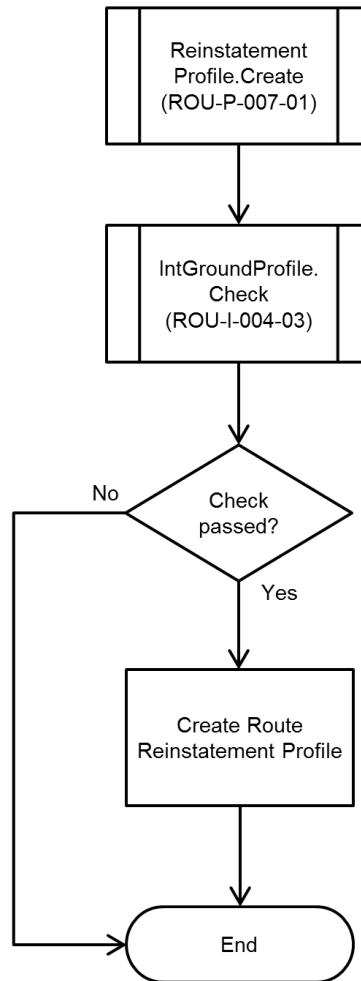


3.9.2.14 HydraulicProfile.Create (ROU-P-006-01)



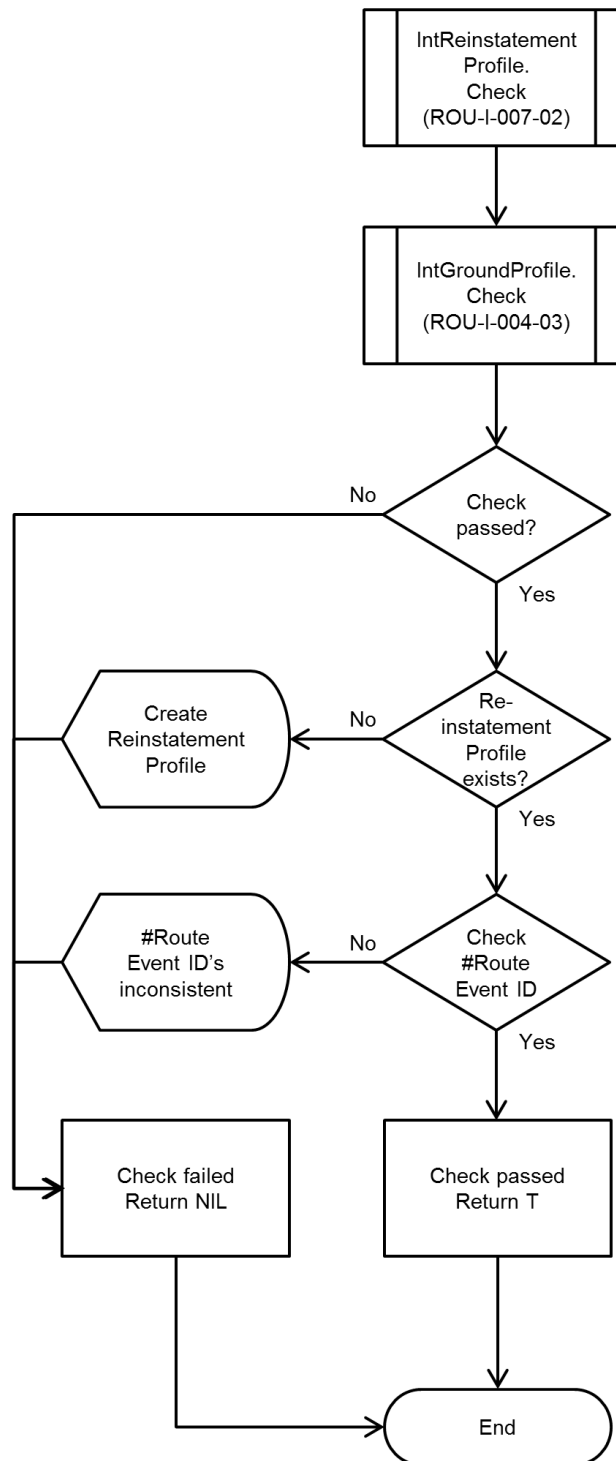


3.9.2.15 *ReinstatementProfile.Create* (ROU-P-007-01)





3.9.2.16 *IntReinstatementProfile.Check (ROU-I-007-02)*

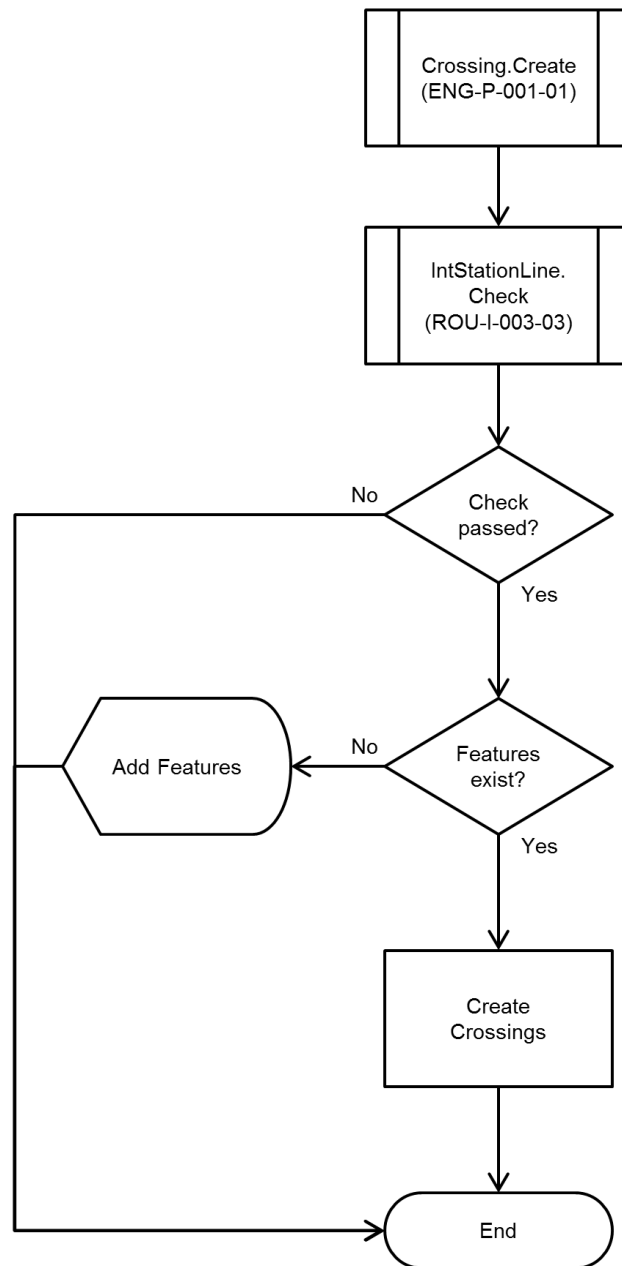




3.9.3 Engineering Functions (ENG)

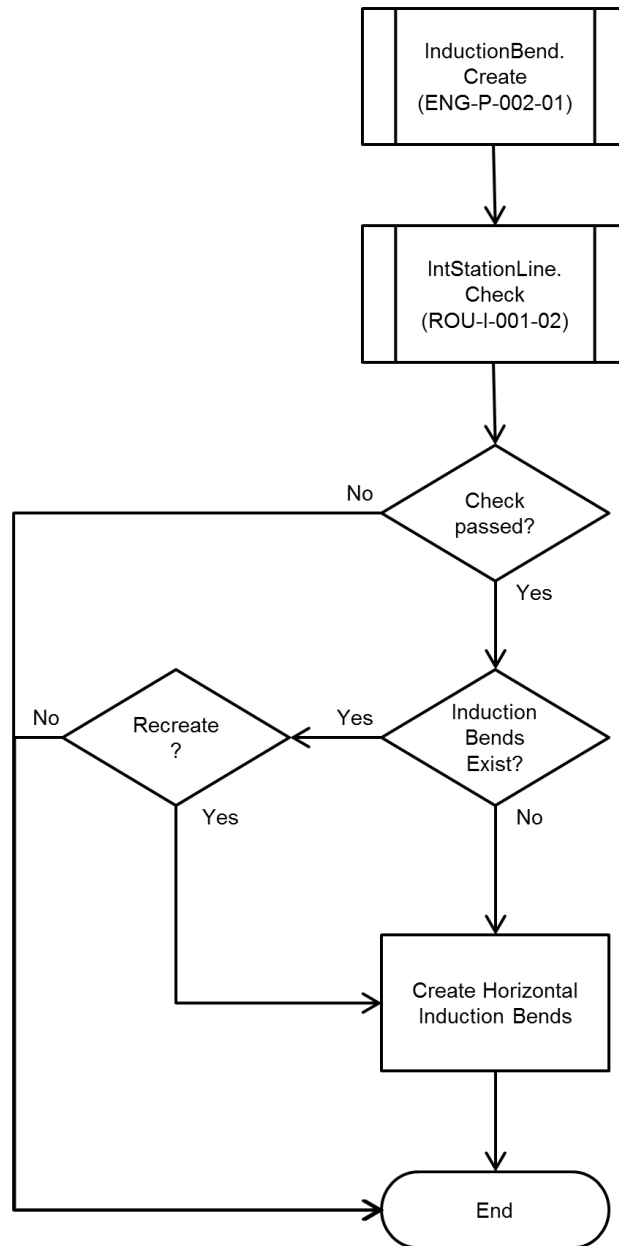


3.9.3.1 Crossing.Create (ENG-P-001-01)



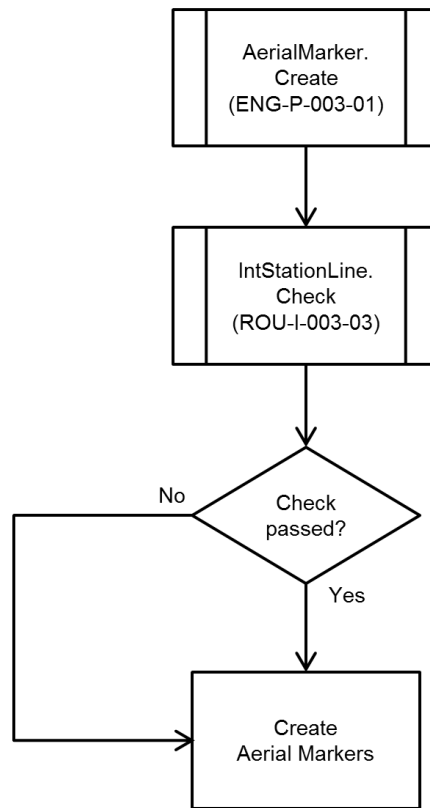


3.9.3.2 *InductionBend.Create* (ENG-P-002-01)



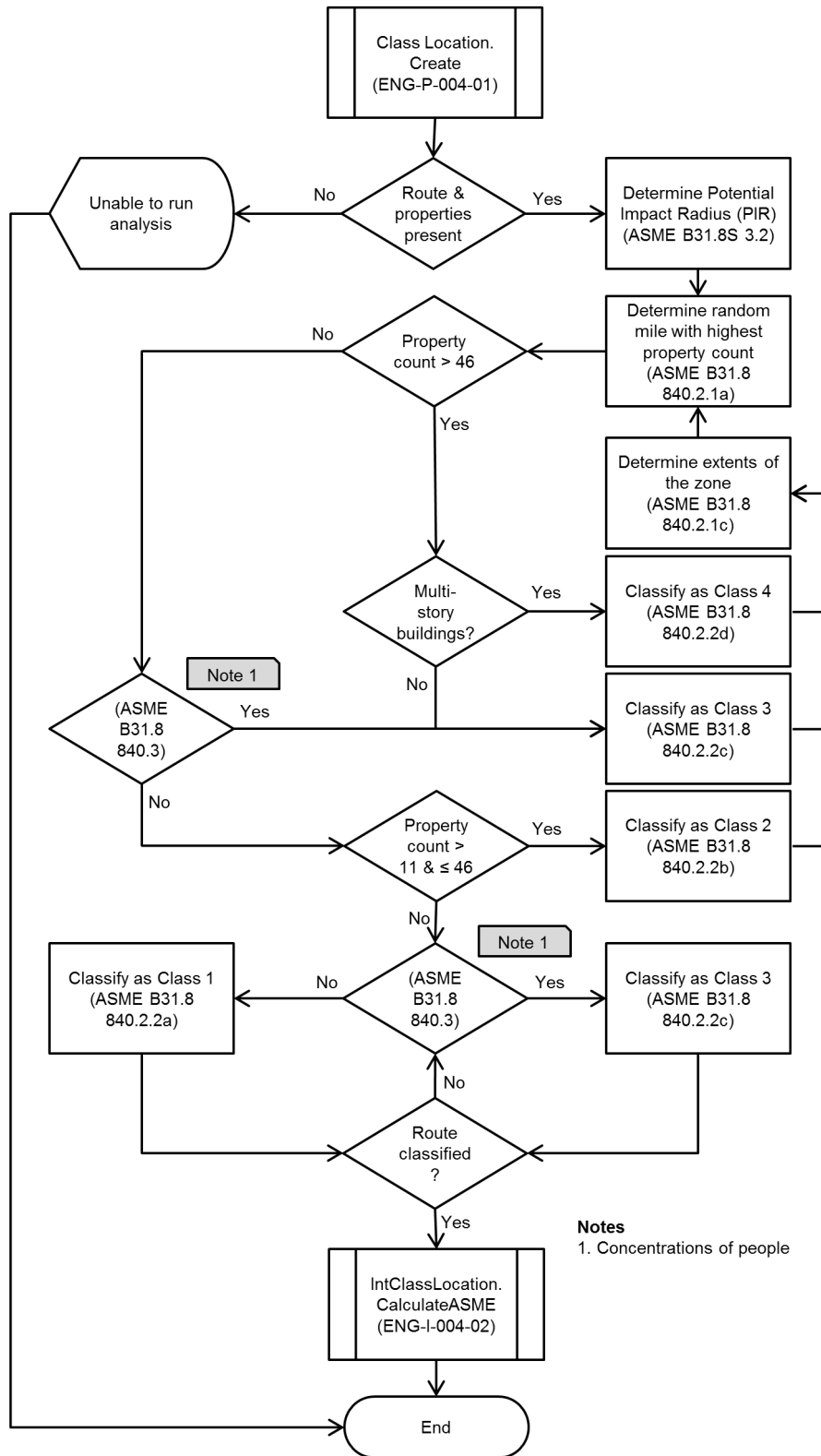


3.9.3.3 *AerialMarker.Create* (ENG-P-003-01)



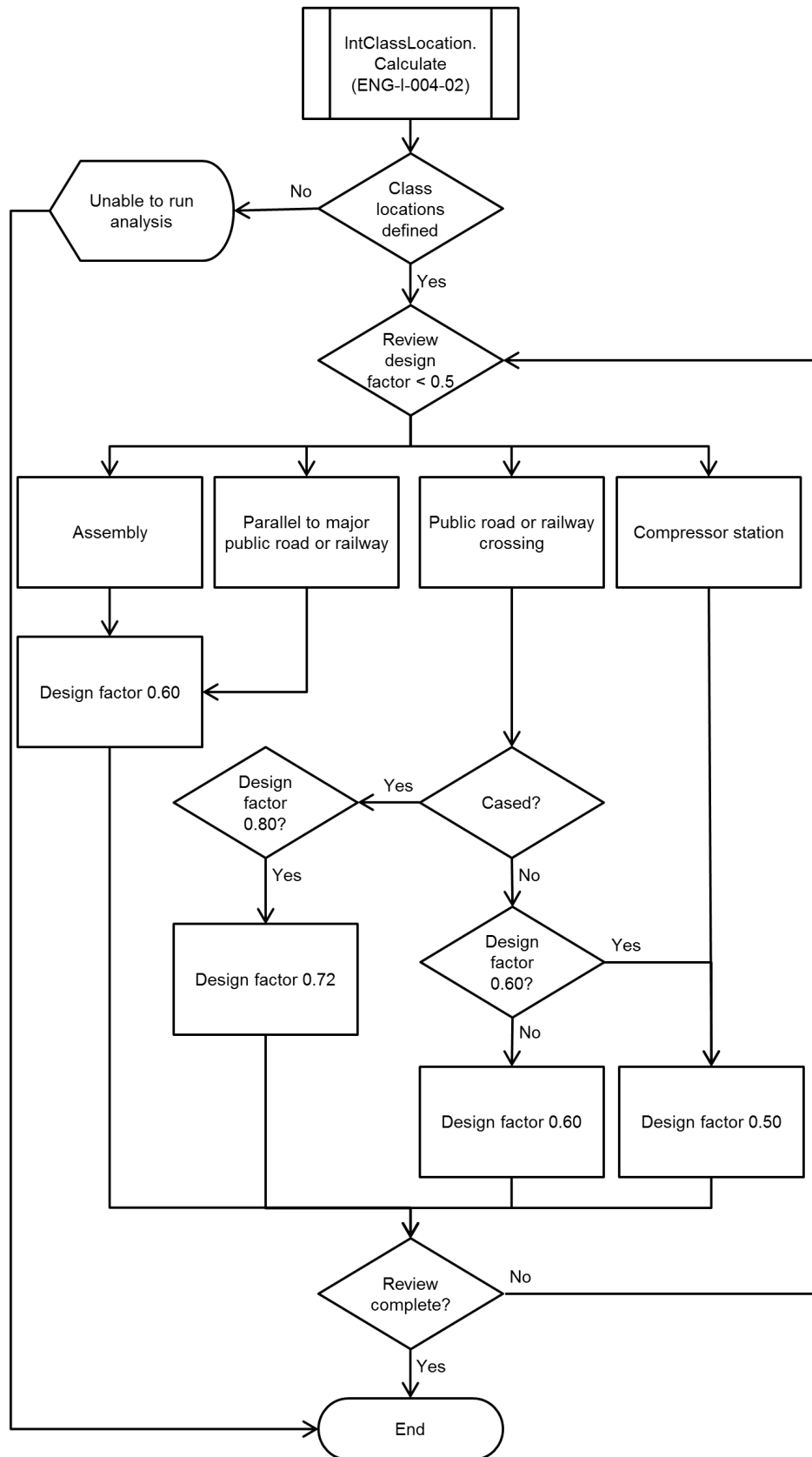


3.9.3.4 ClassLocation.Create (ENG-P-004-01)



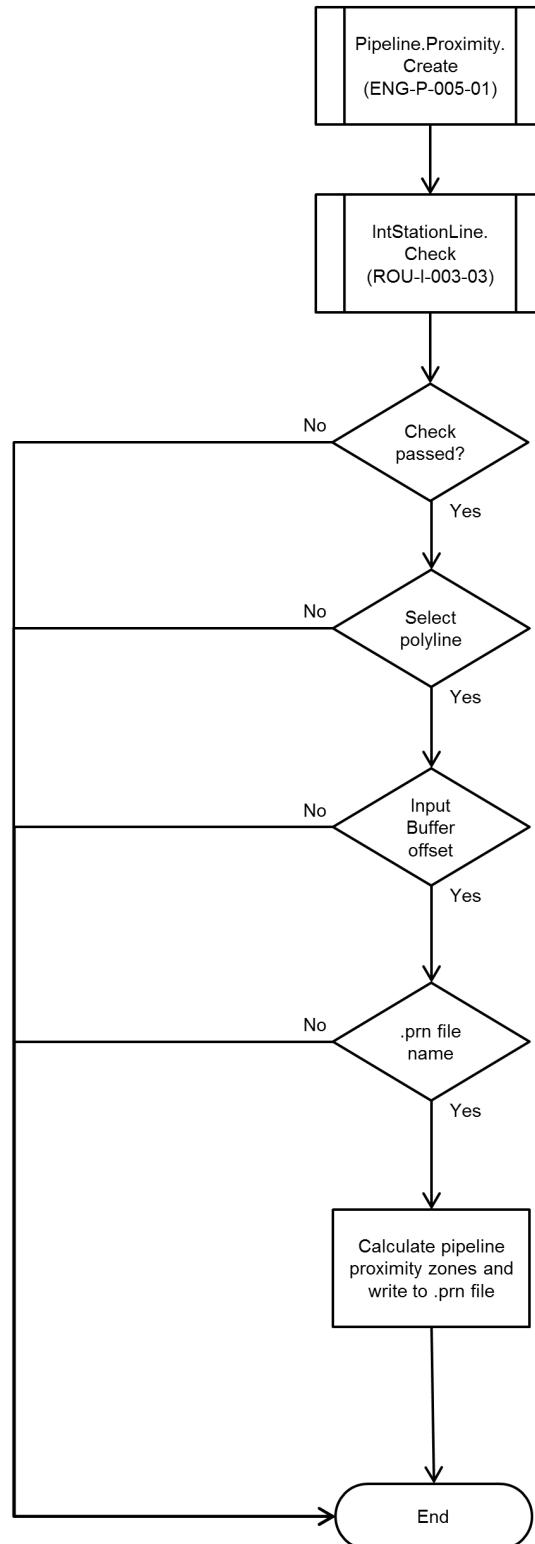


3.9.3.5 *IntClassLocation.Calculate* (ENG-P-004-02)



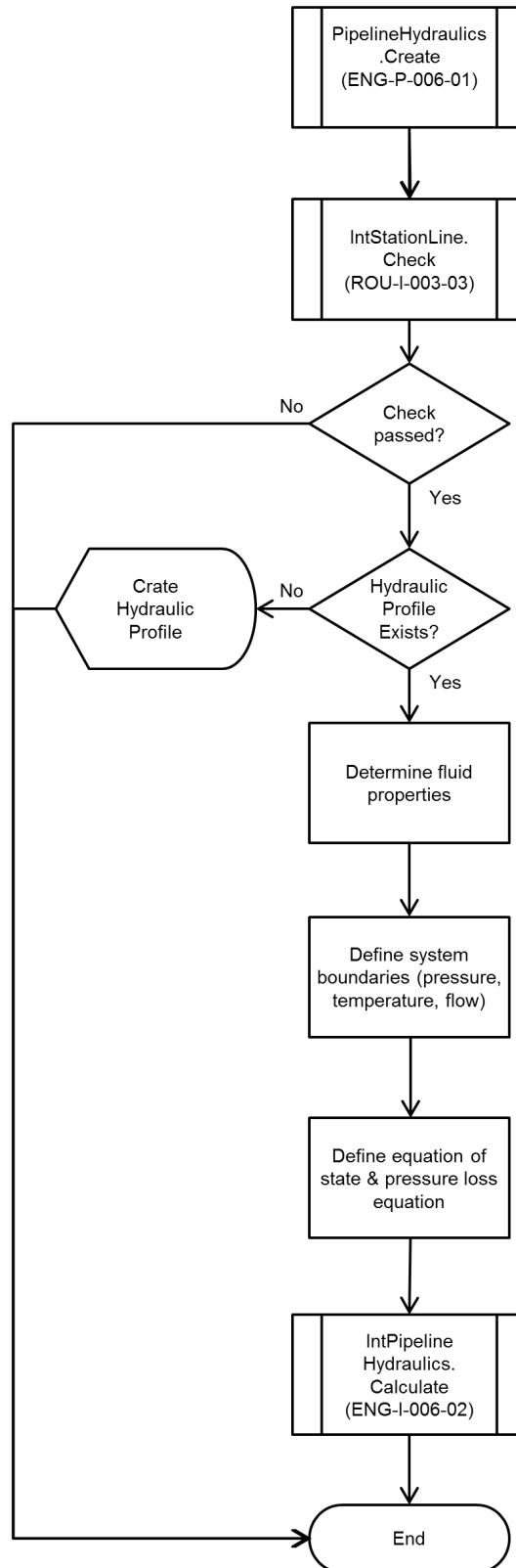


3.9.3.6 PipelineProximity.Create (ENG-P-005-01)



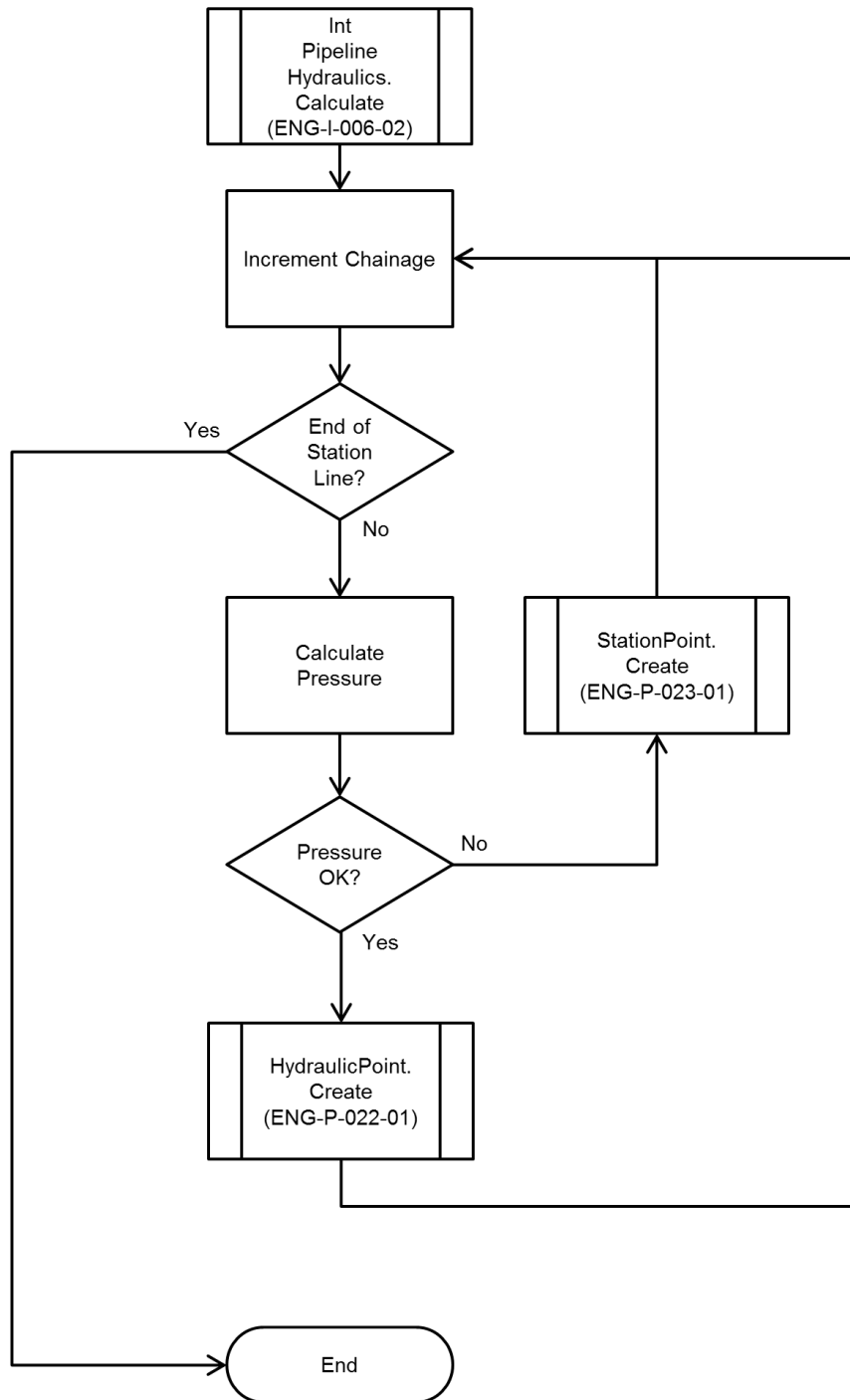


3.9.3.7 PipelineHydraulics.Create (ENG-P-006-01)



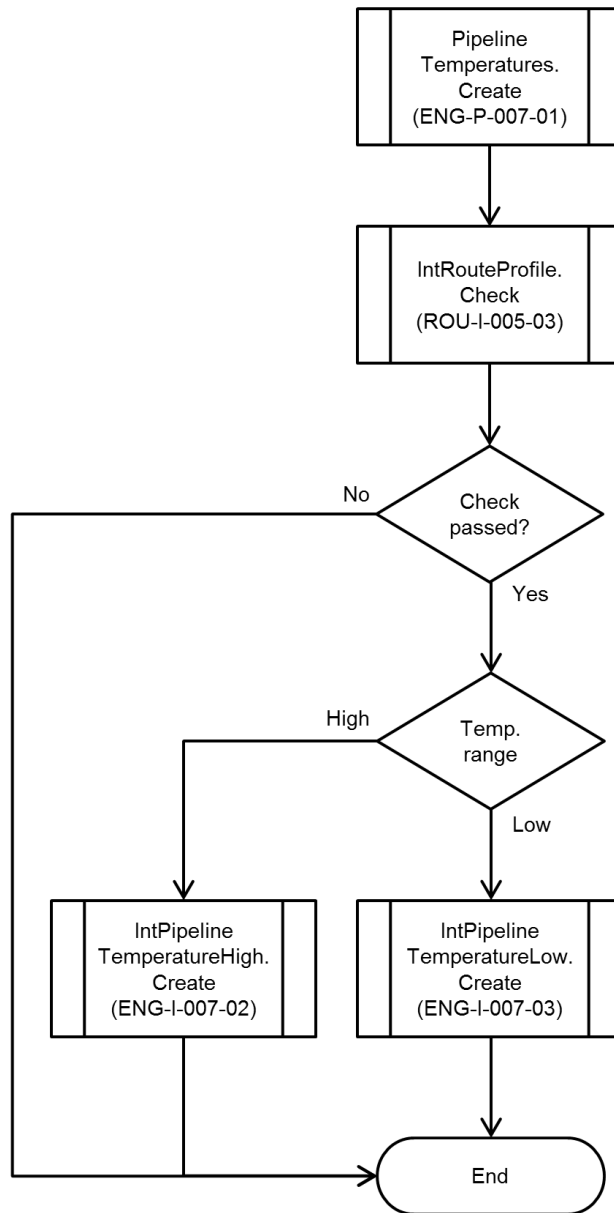


3.9.3.8 *IntPipelineHydraulics.Calculate (ENG-I-006-02)*



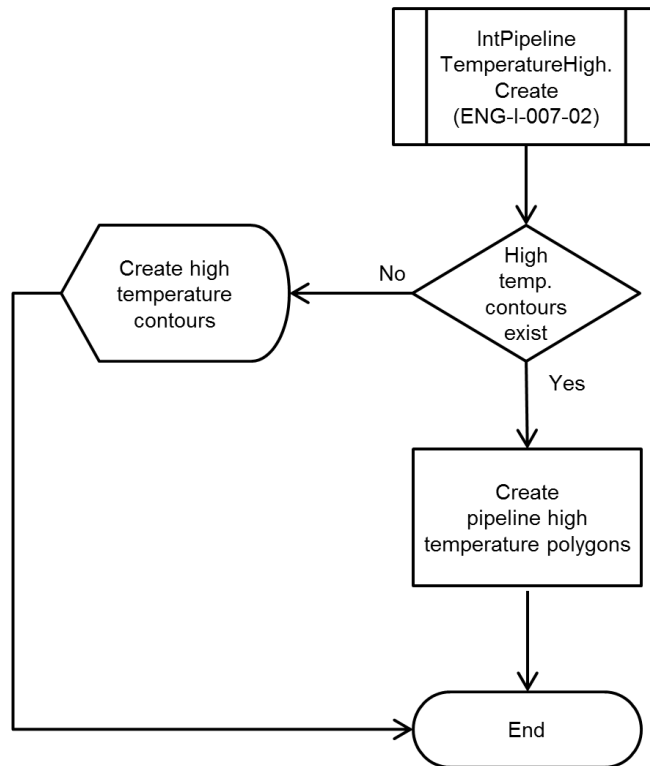


3.9.3.9 PipelineTemperature.Create (ENG-P-007-01)



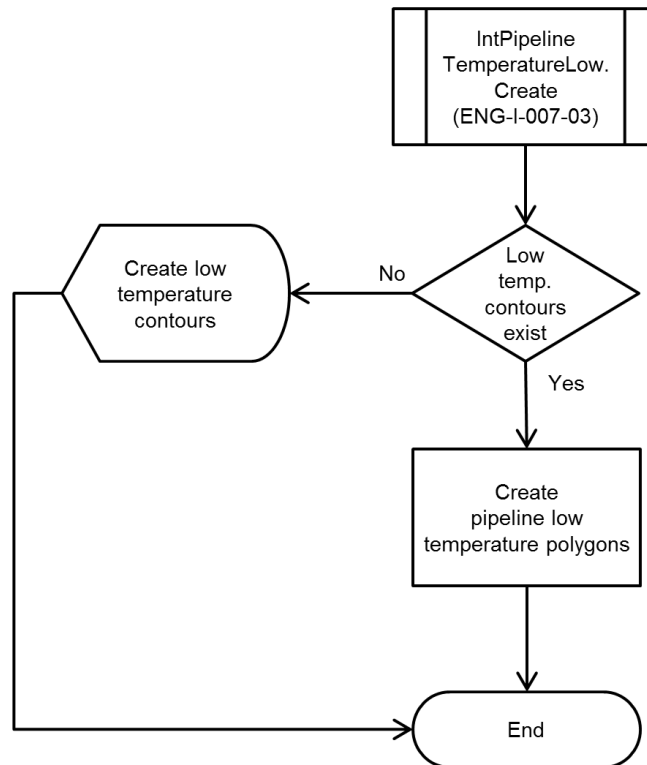


3.9.3.10 *IntPipelineTemperatureHigh.Create (ENG-I-007-02)*



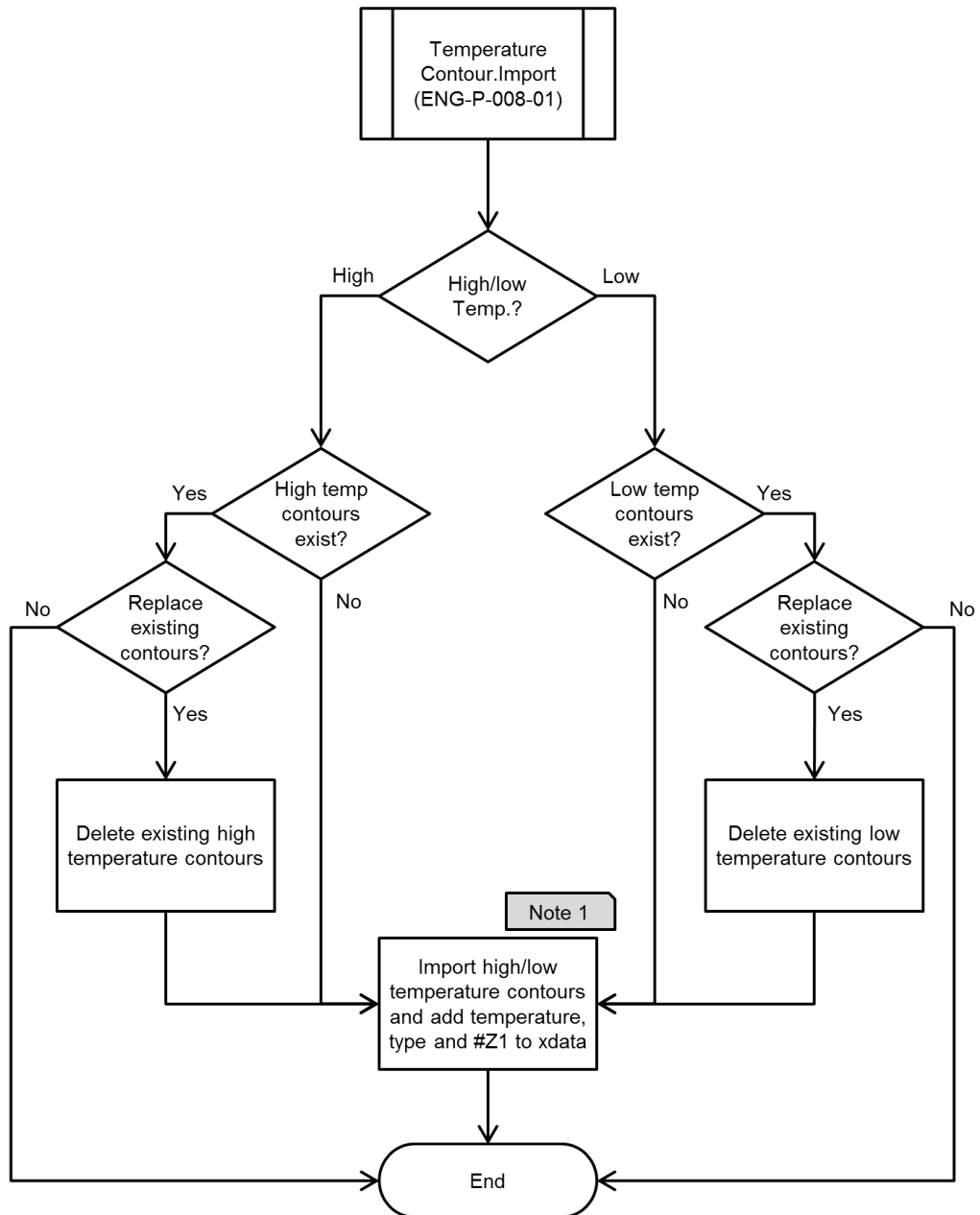


3.9.3.11 *IntPipelineTemperatureLow.Create* (ENG-I-007-03)





3.9.3.12 TemperatureContour.Import (ENG-P-008-01)

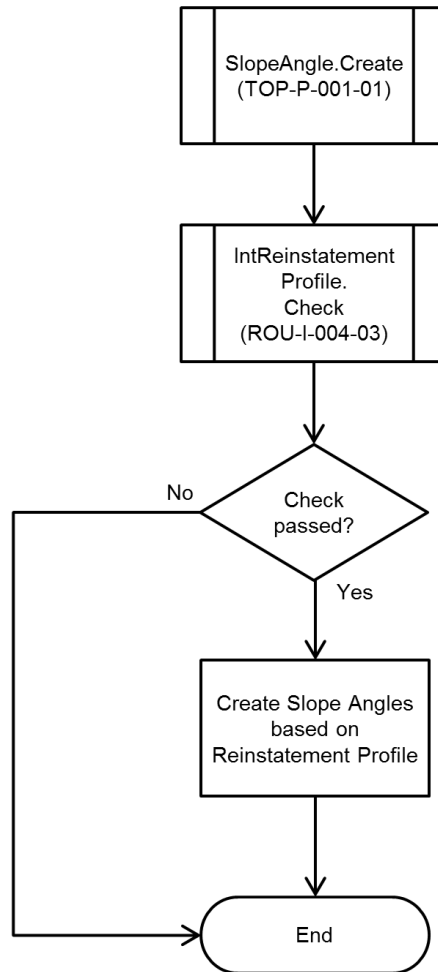




3.9.4 Topography Functions (TOP)

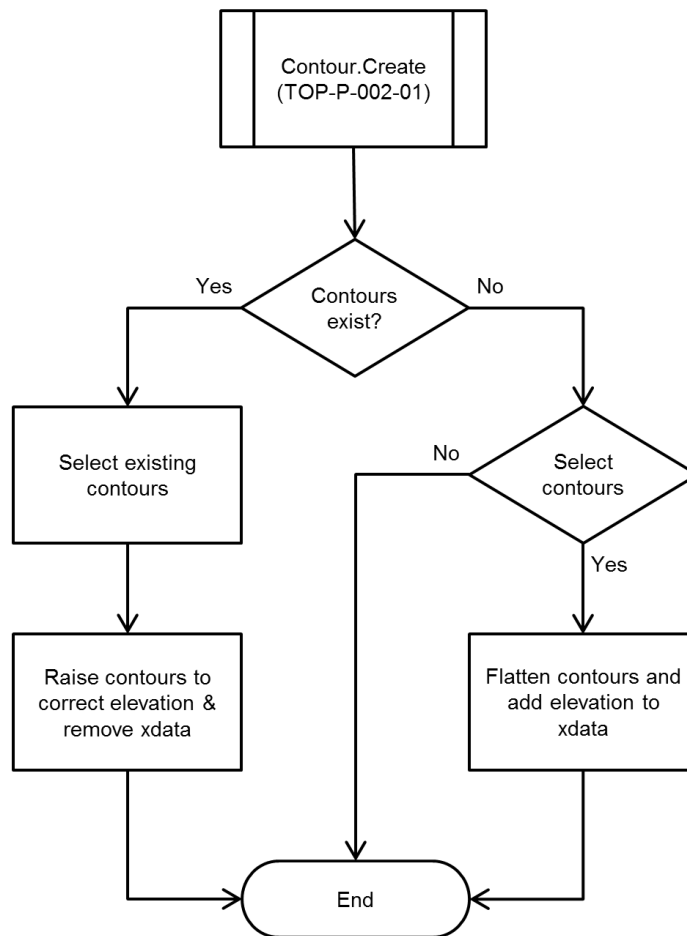


3.9.4.1 *SlopeAngle.Create* (TOP-P-001-01)





3.9.4.2 Contour.Create (TOP-P-002-01)

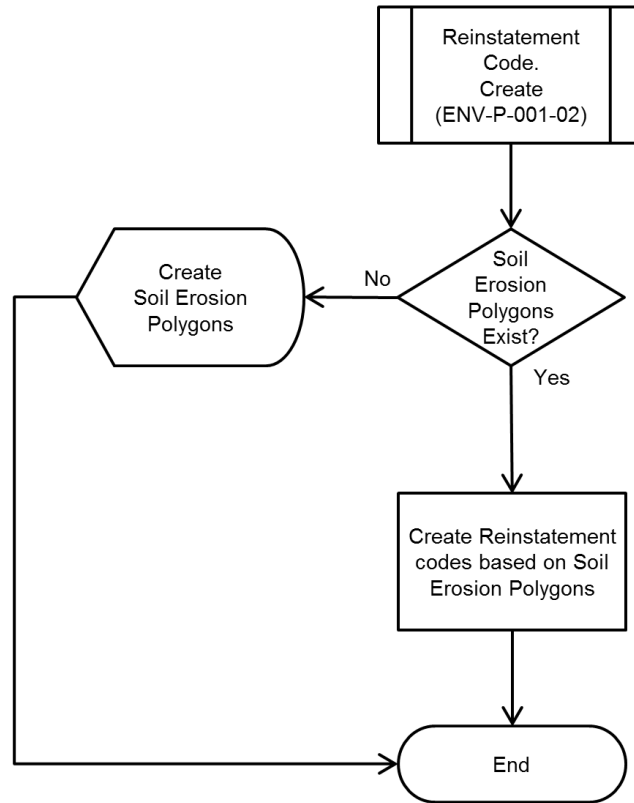




3.9.5 Environmental Functions (ENV)

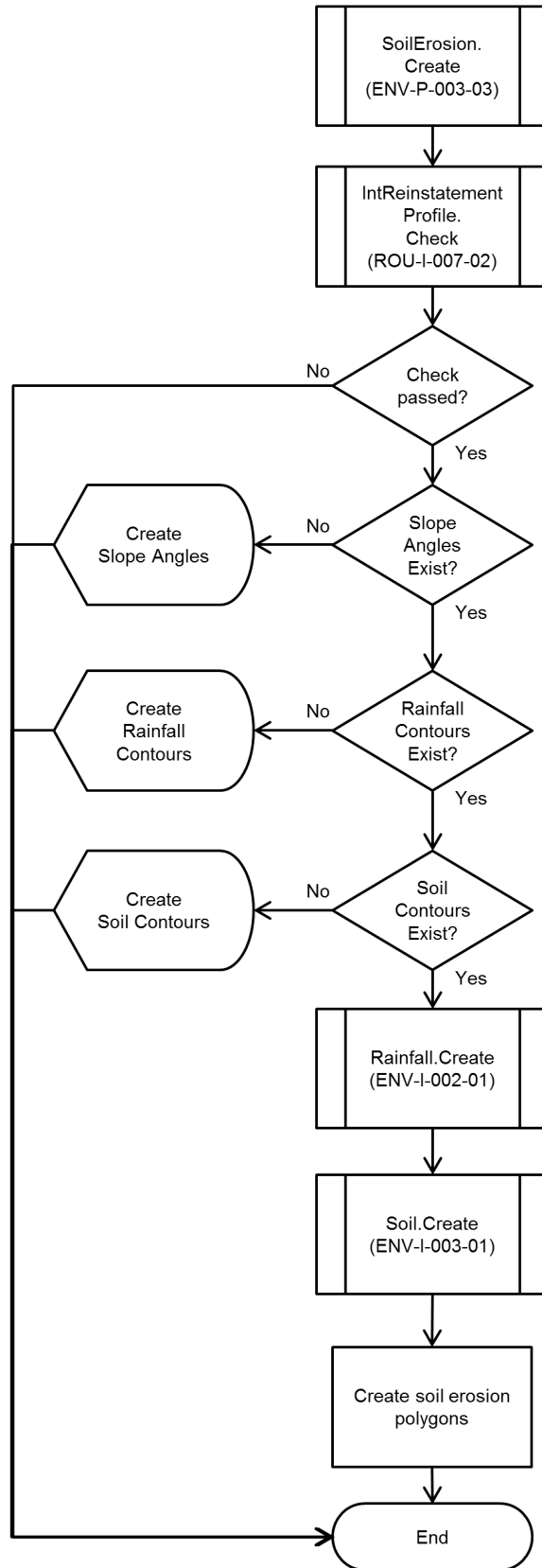


3.9.5.1 *ReinstatementCode.Create (ENV-P-001-02)*





3.9.5.2 SoilErosion.Create (ENV-P-003-03)

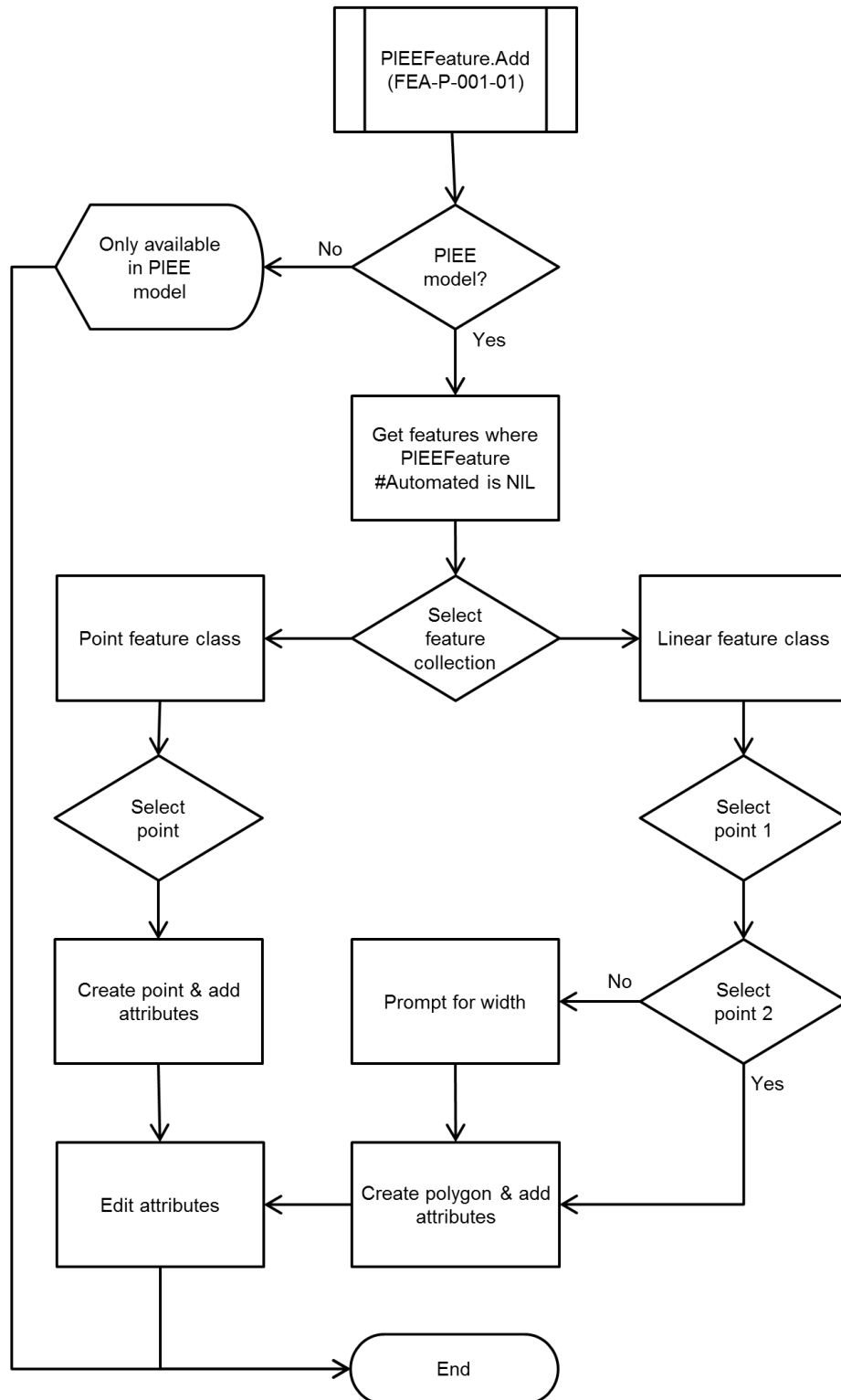




3.9.6 Feature Functions (FEA)

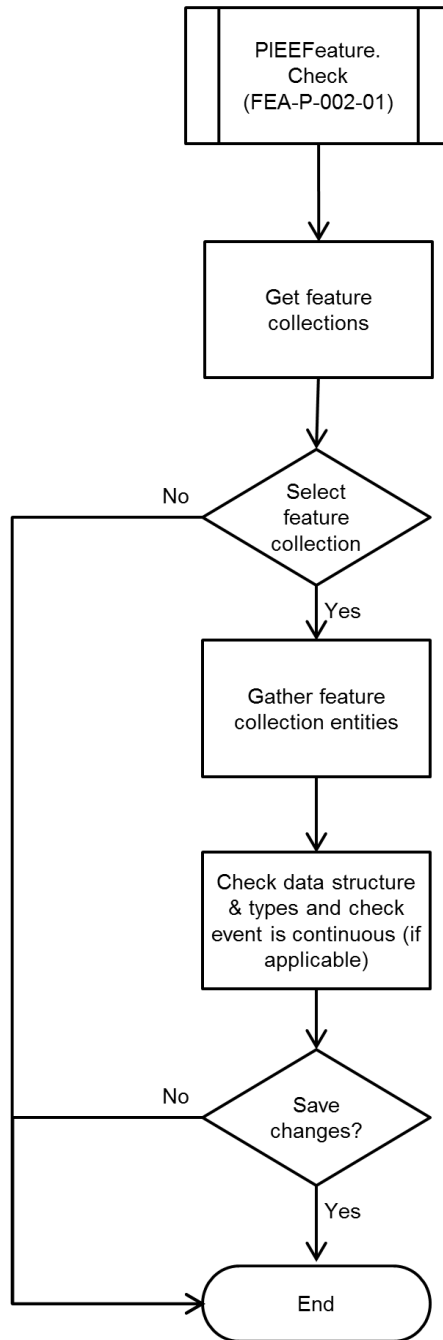


3.9.6.1 Feature.Add (FEA-P-001-01)



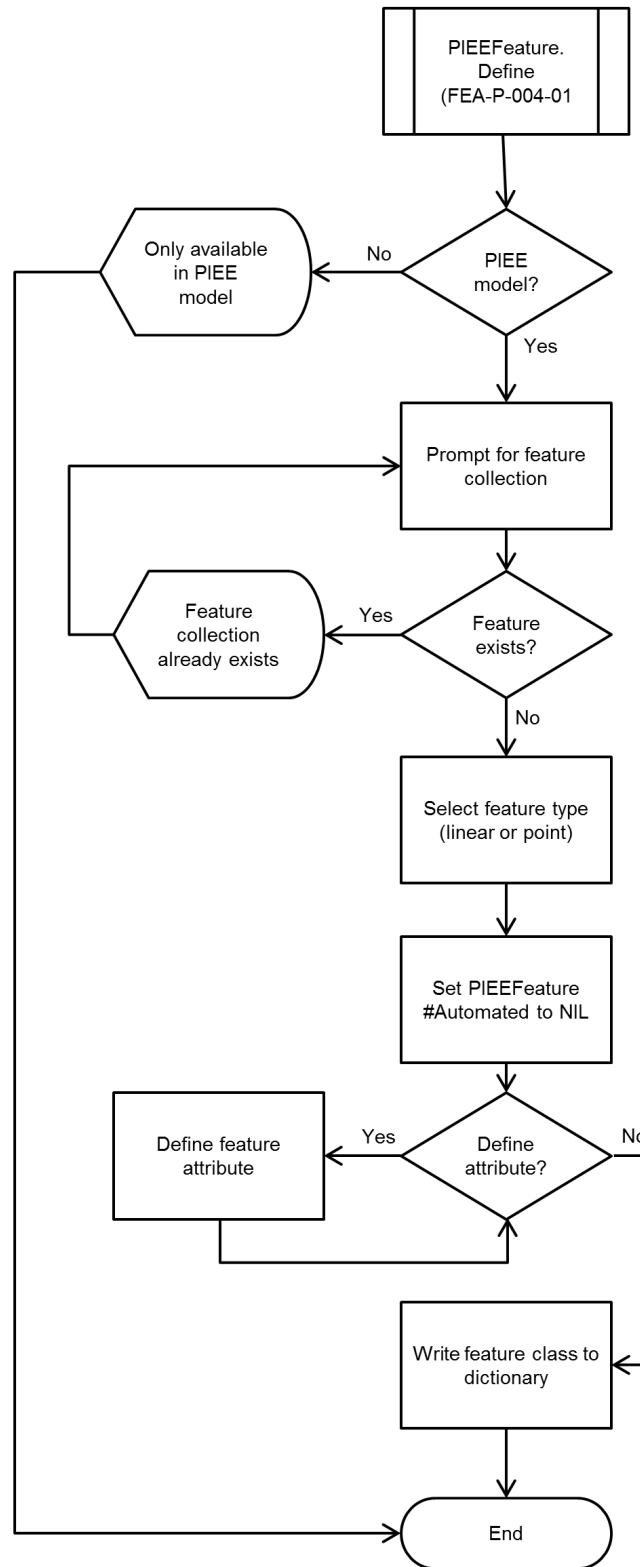


3.9.6.2 Feature.Check (FEA-P-002-01)



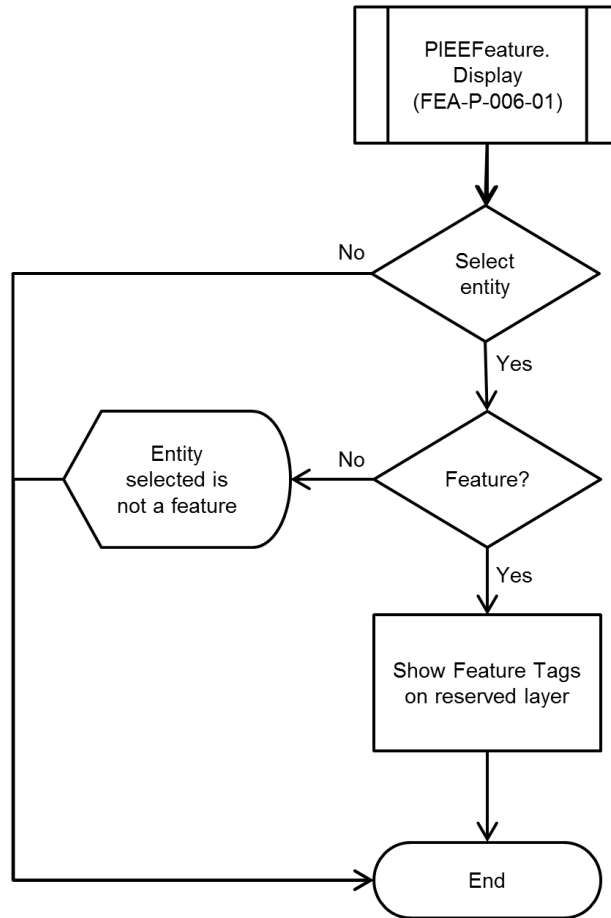


3.9.6.3 Feature.Define (FEA-P-004-01)



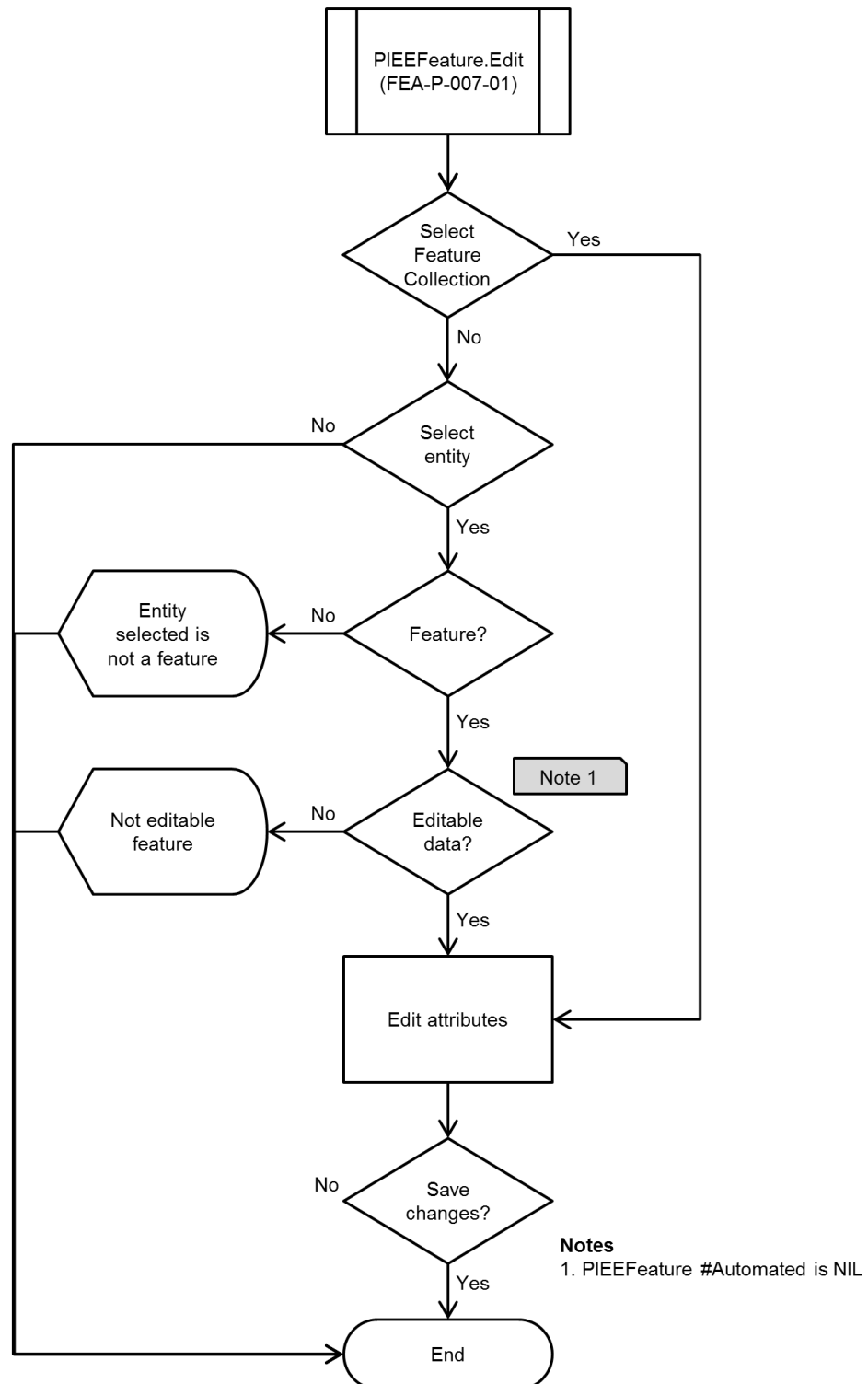


3.9.6.4 *Feature.Display (FEA-P-006-01)*



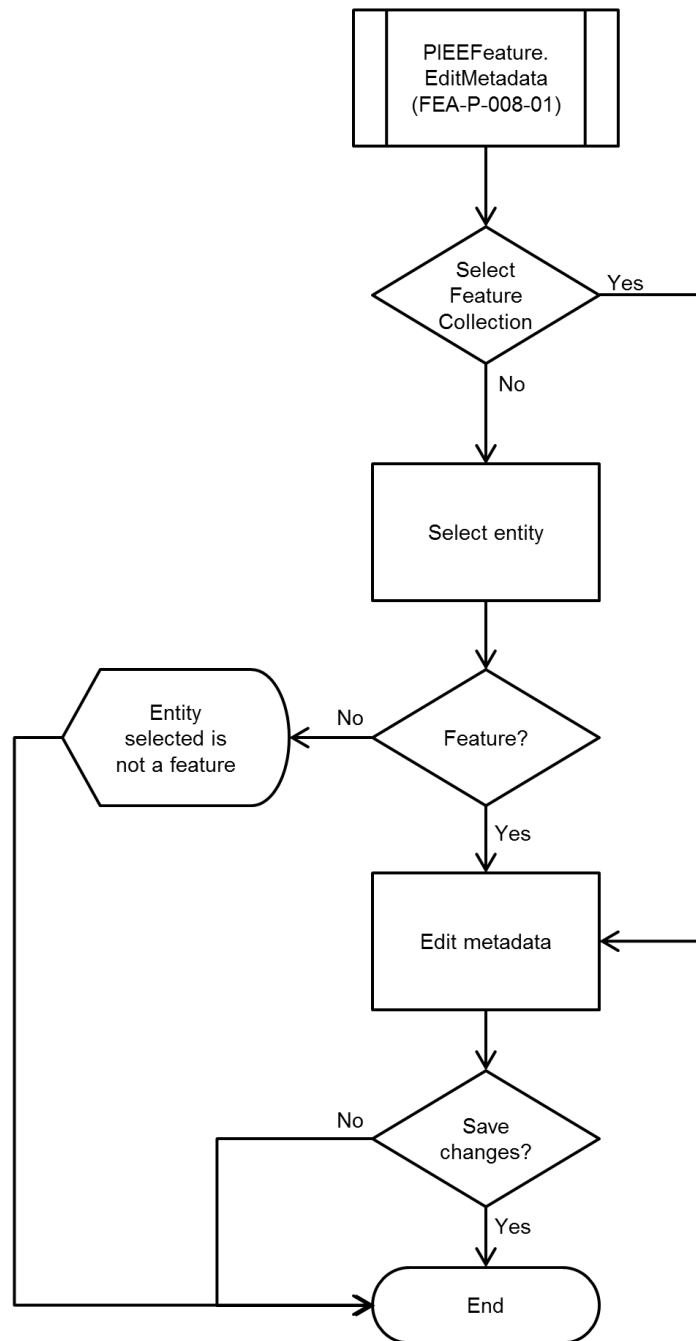


3.9.6.5 Feature.Edit (FEA-P-007-01)



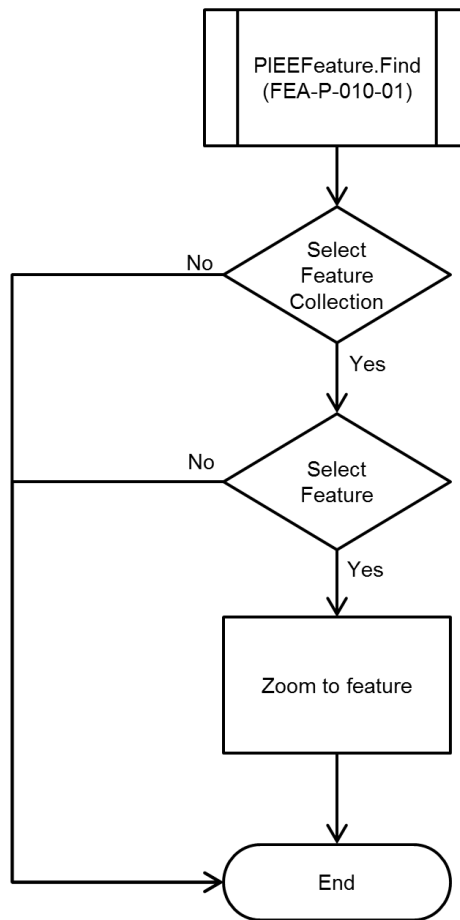


3.9.6.6 *Feature.EditMetadata* (FEA-P-008-01)



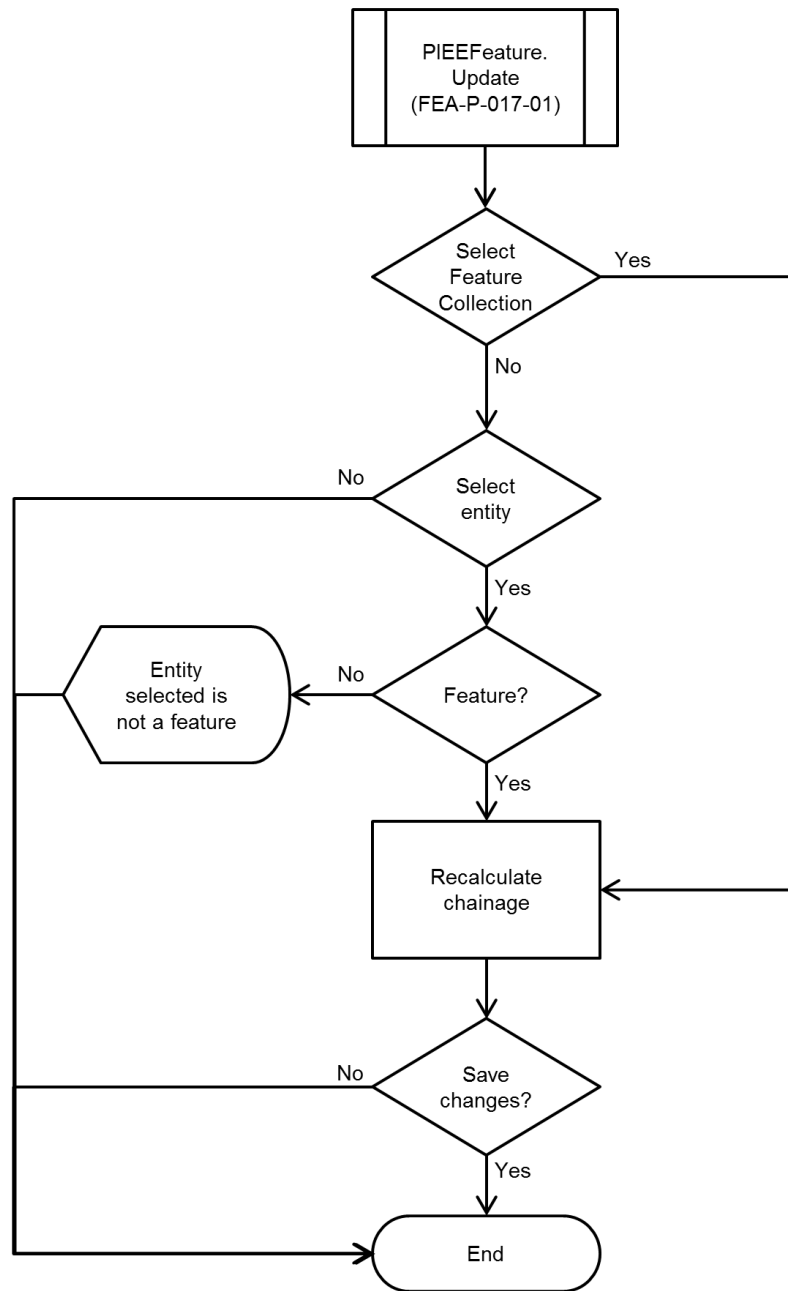


3.9.6.7 *Feature.Find* (FEA-P-010-01)



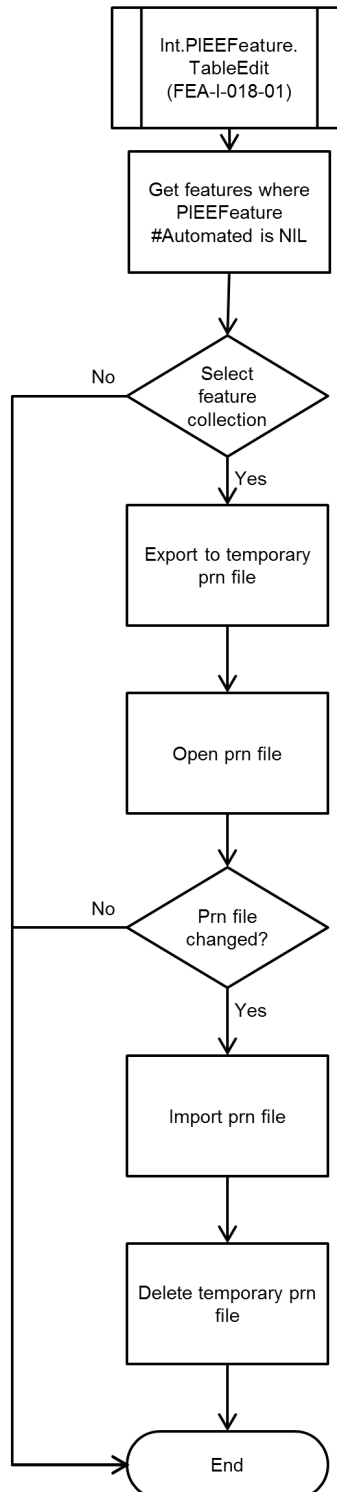


3.9.6.8 Feature.Update (FEA-P-017-01)



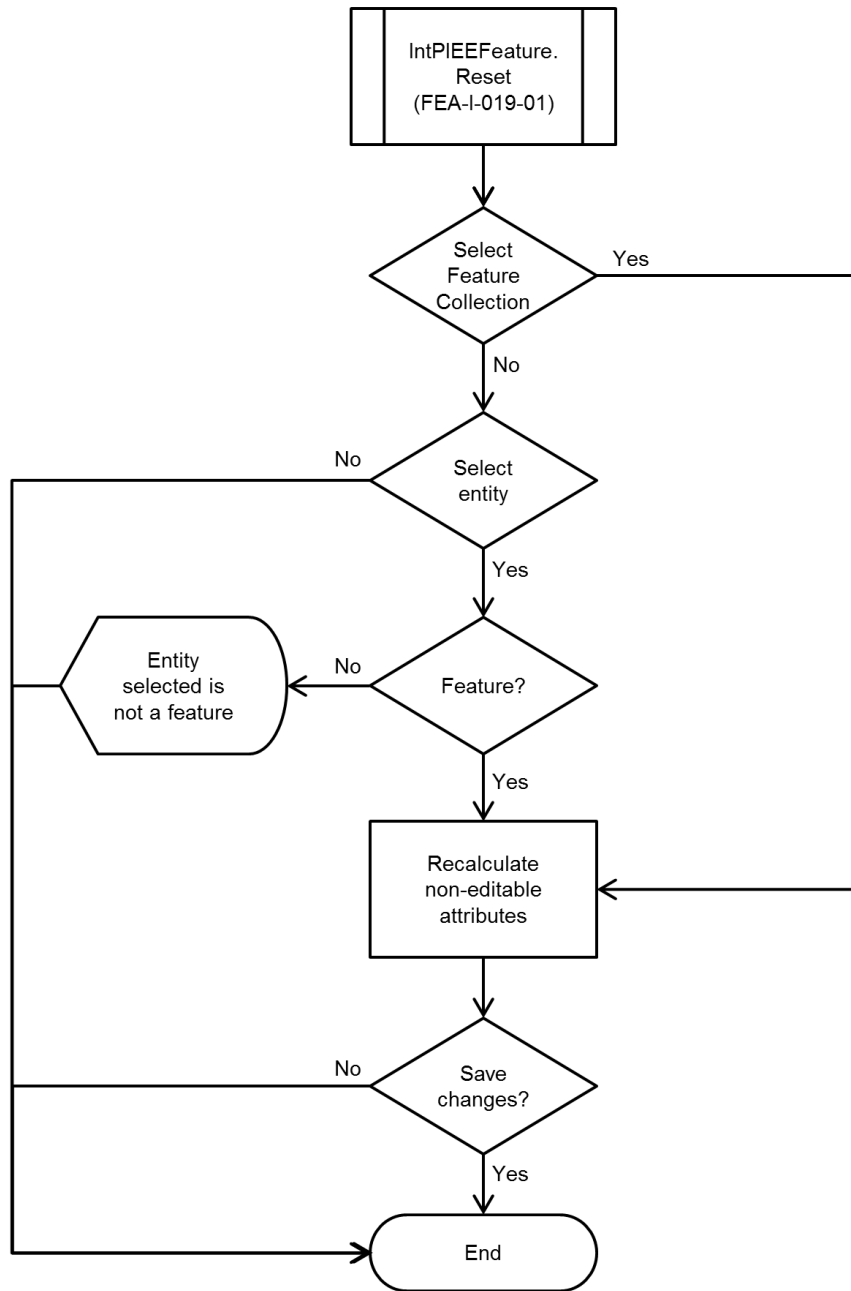


3.9.6.9 Feature.TableEdit (FEA-P-018-01)



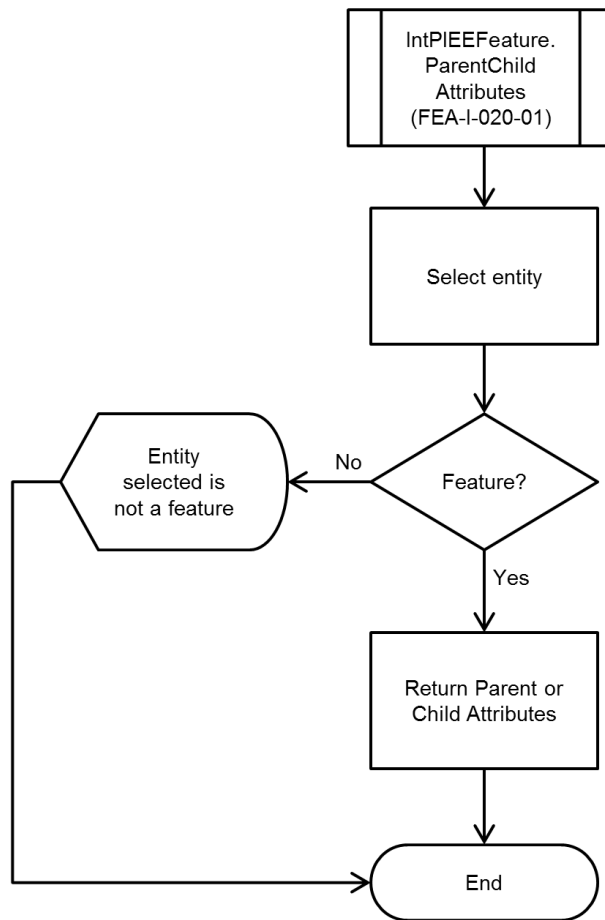


3.9.6.10 IntFeature.Reset (FEA-I-019-01)





3.9.6.11 *IntFeature.ParentChildAttributes* (FEA-I-020-01)

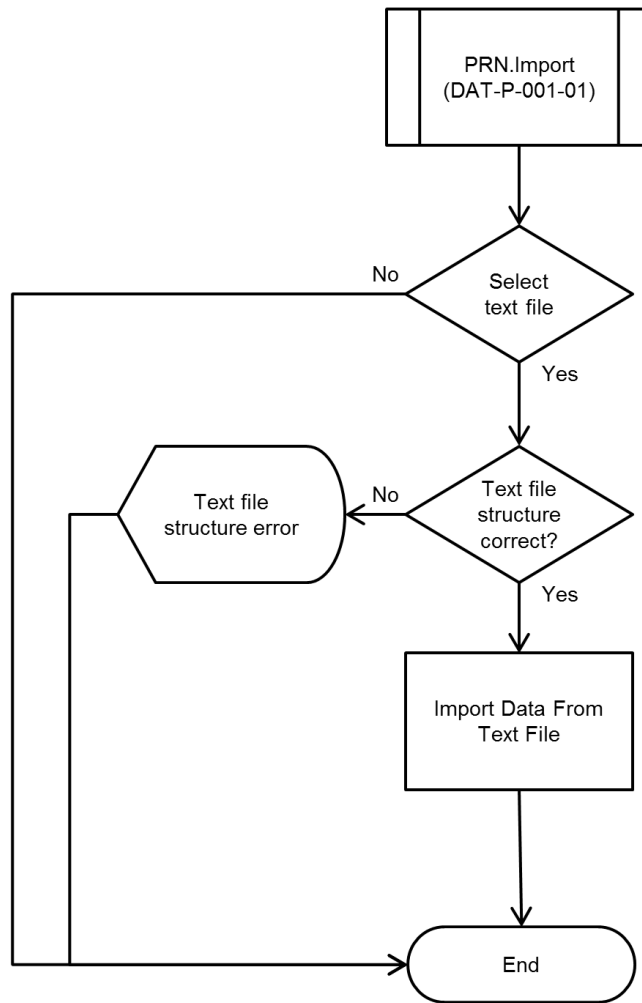




3.9.7 Data Functions (DAT)

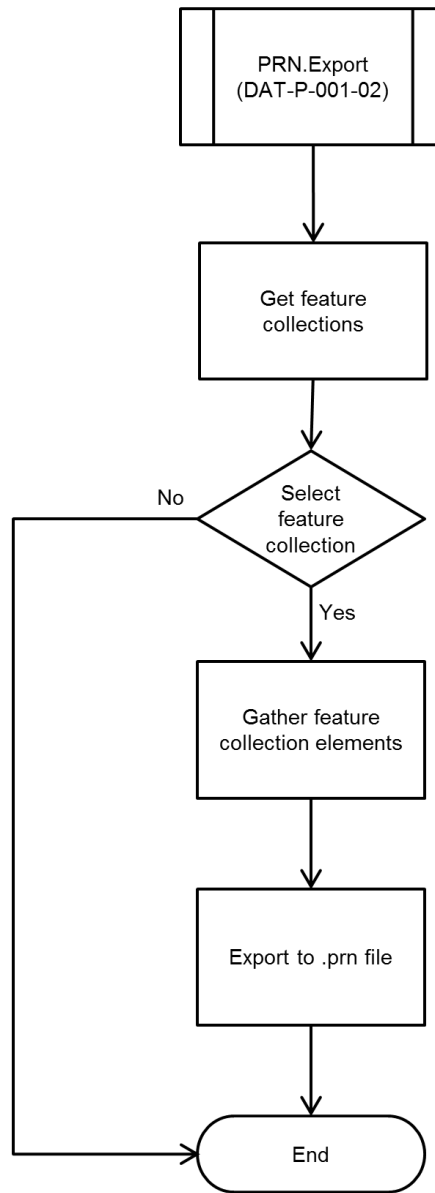


3.9.7.1 PRN.Import (DAT-P-001-01)



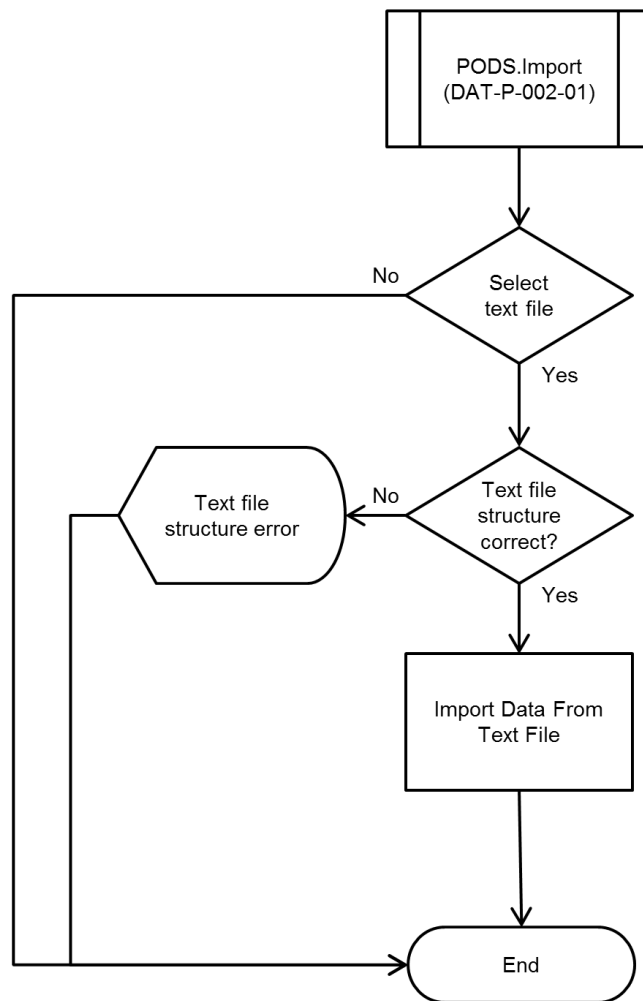


3.9.7.2 PRN.Export (DAT-P-001-02)



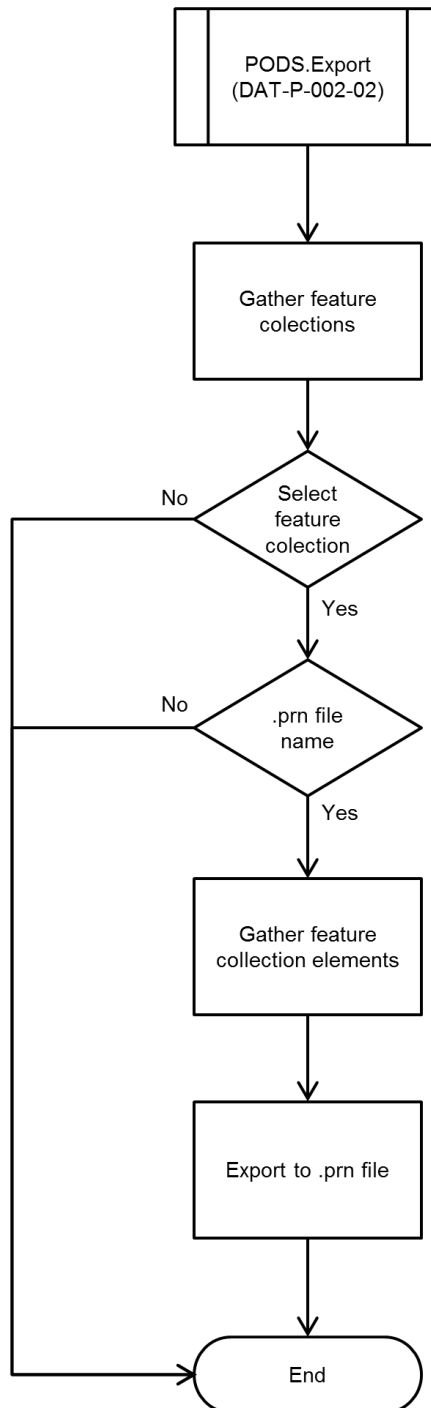


3.9.7.3 *PODS.Import (DAT-P-002-01)*





3.9.7.4 PODS.Export (DAT-P-002-02)

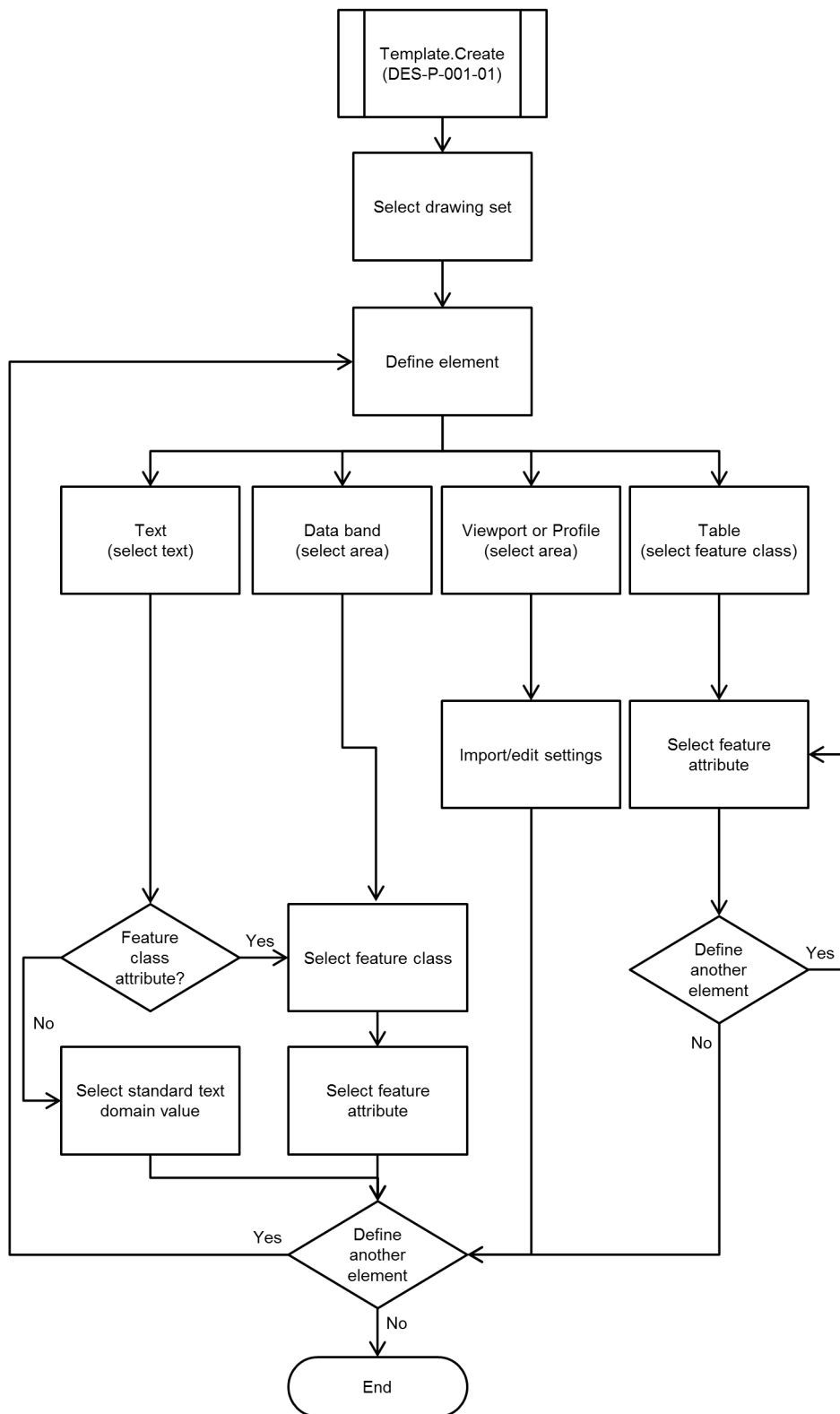




3.9.8 Design Functions (DES)

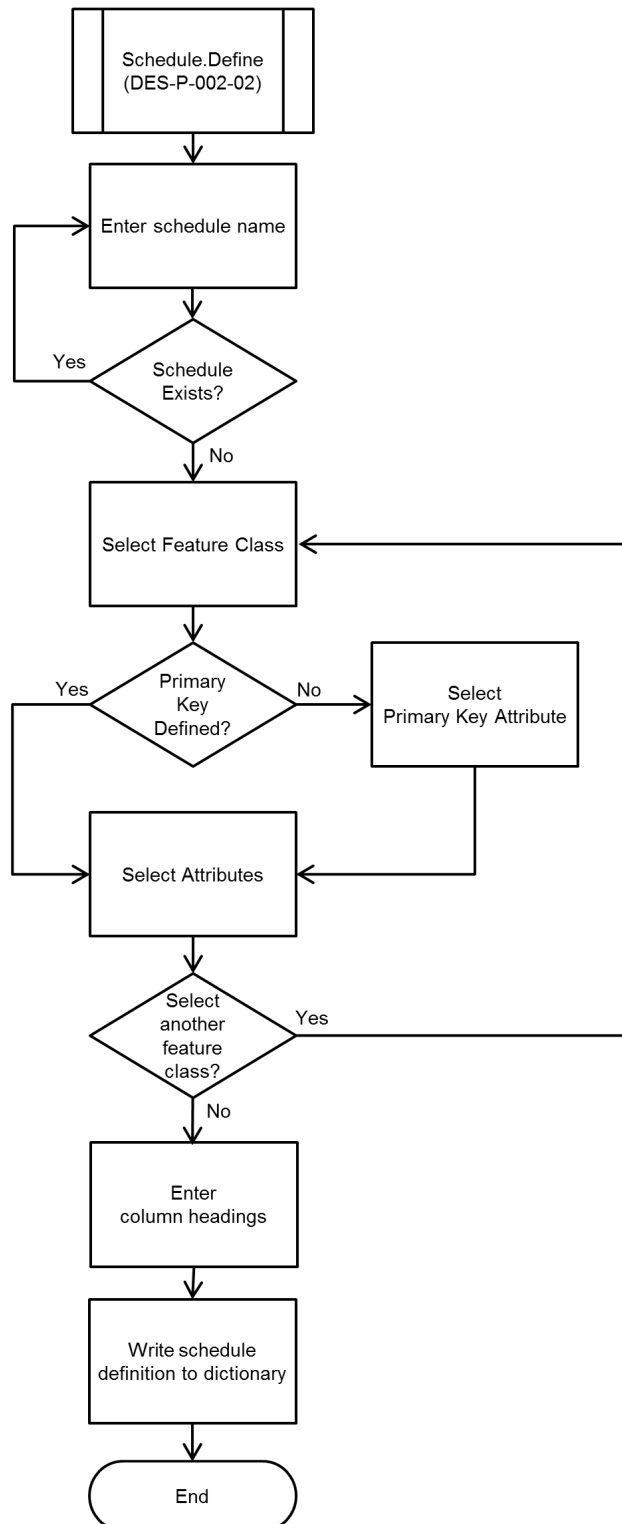


3.9.8.1 *Template.Create (DES-P-001-01)*





3.9.8.2 *Schedule.Define (DES-P-002-02)*





3.10 User Interface

The main user interface for model building and the creation of drawings and reports is through the AutoCAD interface. A partial AutoCAD menu (PIEE.cui) has been created with tabs titled, 'PIEE Model' and 'PIEE Design'. The menu is supported by an AutoLISP file (PIEE.mnl) which performs the necessary function to initialise the PIEE system. Standard representations have been used where appropriate for common methods such as add, create, define, delete, check etc.

3.10.1 Modelling

The PIEE Model ribbon tab provides the user with access to the all the main functions required to create and manage the model. The following figure shows a screen shot of the PIEE Model ribbon tab within the AutoCAD environment.

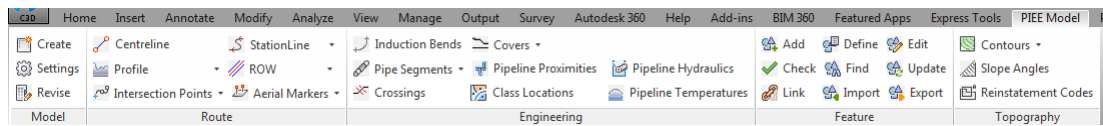


Figure 3.1 – PIEE AutoCAD Menu (PIEE Model Ribbon Tab)

The PIEE Model ribbon tab is further broken down into the following panels, grouping the controls by functional requirement:

Model Panel - contains PIEE functions to create a new model, revise an existing model and edit model settings via the model settings dialog box. The model settings dialog box will also include a toggle to lock or unlock the model for editing.

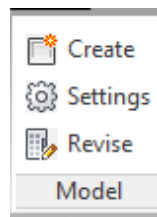


Figure 3.2 – Model Panel

Route Panel - contains PIEE functions related to routing features, including: Centreline, StationLine, Profile, ROW, Intersection Points and Aerial Markers.

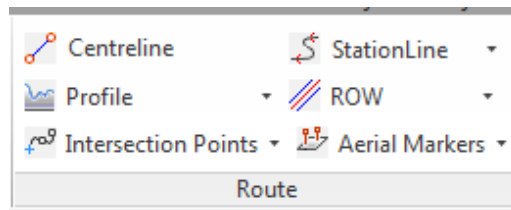


Figure 3.3 – Route Panel



Route Panel - StationLine Drop Down List - Contains available methods for the StationLine feature (Create, Set and Update).

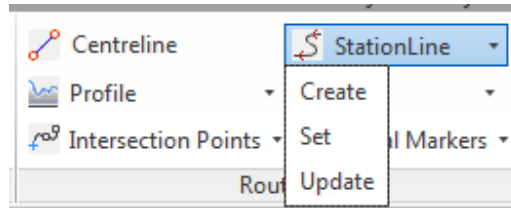


Figure 3.4 – Route Panel, StationLine Drop Down List

Route Panel - Profile Drop Down List - Contains functions to create Ground Profile, Route Profile, Hydraulic Profile and Reinstatement Profile.

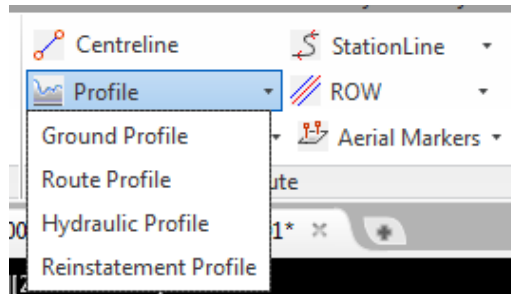


Figure 3.5 – Route Panel, Profile Drop Down List

Route Panel - ROW Drop Down List - Contains available methods for the ROW feature (Add, Create, Delete and Edit).

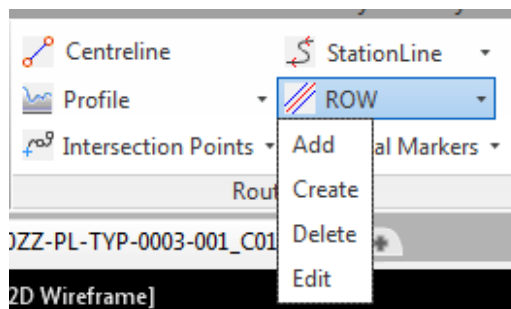


Figure 3.6 – Route Panel, ROW Drop Down List

Route Panel – Intersection Points Drop Down List - Contains available methods for the Intersection Point feature (Create, Edit and Update).

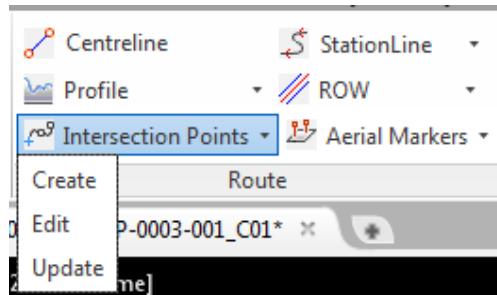


Figure 3.7 – Route Panel, Intersection Points Drop Down List

Route Panel – Aerial Markers Drop Down List - Contains available methods for the Aerial Marker feature (Create, Edit and Update).

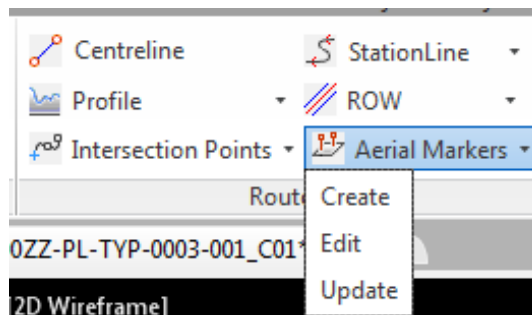


Figure 3.8 – Route Panel, Aerial Markers Drop Down List

Engineering Panel - contains PIEE functions related to engineering features, includes: Induction Bends, Pipe Segments, Crossings, Covers, Pipeline Proximities, Class Locations, Pipeline Hydraulics and Pipeline Temperatures.

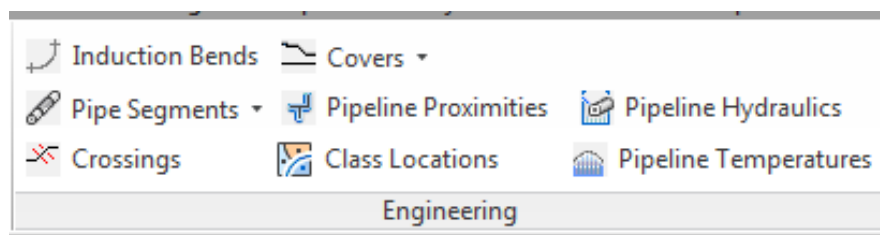


Figure 3.9 – Engineering Panel



Engineering Panel – Pipe Segments Drop Down List - Contains available methods for the Pipe Segment feature (Add, Create, Delete and Edit).

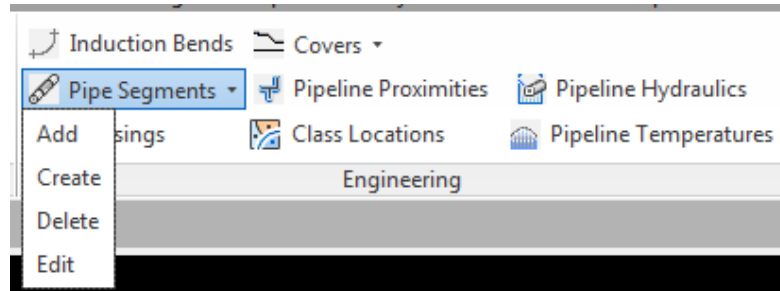


Figure 3.10 – Engineering Panel, Pipe Segments Drop Down List

Engineering Panel – Covers Drop Down List - Contains available methods for the Cover feature (Add, Create, Delete and Edit).

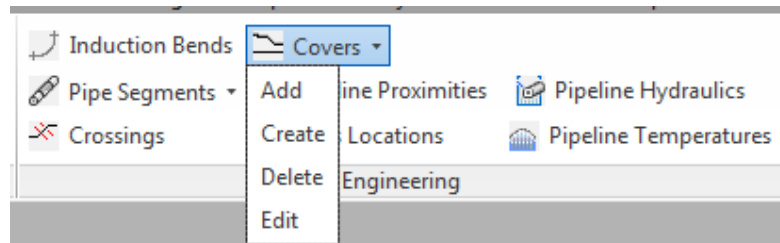


Figure 3.11 – Engineering Panel, Covers Drop Down List

Feature Panel – contains PIEE feature methods. Each button will open a dialog box that will present the user with a list of features which the method applies to, includes: Add, Define, Edit, Check, Find, Update, Link, Import and Export.

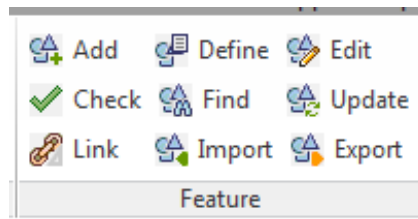


Figure 3.12 – Feature Panel

Topography Panel – contains PIEE functions related to topographical features, includes: Contours, Slope Angles and Reinstatement Codes.

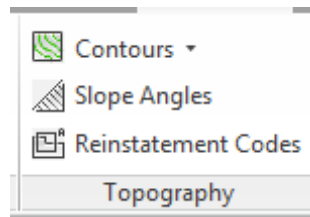


Figure 3.13 – Topography Panel

Topography Panel – Contours Drop Down List - Contains available methods for the Contour feature (Create and Import).

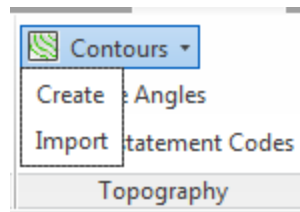


Figure 3.14 – Topography Panel, Contours Drop Down List

3.10.2 Design and Reporting

Similar to the modelling interface, the design and reporting interface provides access to the controls for creating, managing and generating drawings and reports. Multiple drawing sets can be automatically generated from the system including:

- Route maps: Plan drawing with a single viewport. Used as an overview of the route as an aid to logistics, planning and site access. (Appendix A1).
- Strip maps: Plan drawing with two viewports. These are of two types:
 - Type A: The area covered in each viewport is different, enabling a consolidated set of drawings to cover the entire pipeline route, although with less extensive detail than the route maps. Used as an aid during route walks. (Appendix A2).
 - Type B: The area covered in each viewport is the same, with the viewports containing different background imagery for the same extents. Used during route walks and as an aid for topographically based analysis, such as soil erosion risk assessment. (Appendix A3).



- Engineering alignment sheet: An alignment sheet showing all the required engineering, environmental and geotechnical information for the tertiary design and construction of the pipeline route. The drawing has a plan and a differentially scaled ground profile, cut as required. The engineering and environmental information is shown in data bands below the profile. The drawing also provides details of all the physical and third party features crossed. (Appendix A4).
- Reinstatement assessment drawing: A modified form of alignment sheet. The engineering and environmental data bands below the profile are replaced with the calculated inputs for the Universal Soil Loss Equation (USLE) used to perform the preliminary soil erosion risk assessment from the remote sensed data and the estimated soil loss. Additional blank rows are provided for field observation. These drawings currently have no equivalent, and are produced to aid the soil erosion risk assessment field investigation. (Appendix A5).
- Environmental alignment sheet: A modified form of alignment sheet. Similar to the reinstatement assessment drawing, it only displays information relating to the environmental constraints, while providing room for the capture of field notes. (Appendix A6).
- Cadastral alignment sheet: A modified form of alignment sheet. The engineering and environmental data bands below the profile are replaced with the owner and occupier book of reference (BoR) numbers and the linear easement and area in square metres for crop compensation. Details of the basis of the crop compensation and identification of land parcels are also included. (Appendix A7).
- Preliminary as-built alignment sheet: A modified form of alignment sheet. This drawing is issued with the last approved for construction (AFC) route in plan, all deviations from this route during the construction phase identified with their respective change request numbers and the as-built centreline based on the weld location and data from the constructors pipe data book. The drawing has a differentially scaled ground and top of pipe profile, cut as required. The coordinates and identification for every weld is provided. This drawing is submitted



to the site engineer for verification of the installed pipeline prior to the submission of any further as-built data from the contractor. (Appendix A8).

- Final as-built alignment sheet: A modified form of alignment sheet. Based on the preliminary as-built alignment sheet, the AFC route and route deviation notices are removed and the final as-built information, including markers, cathodic protection, fibre optic cable details are added. (Appendix A9).
- Standard crossing drawing: A crossing drawing showing all the required engineering, environmental and geotechnical information for the tertiary design and construction of the pipeline crossing. The drawing has a plan and profile at the same scale, with the engineering and environmental requirements shown below the profile in data bands. Construction requirements of minor crossings are covered by standard (typical drawings). Major crossings requiring specialist crossing methods, horizontal directional drilling (HDD), tunnel boring machines (TBM) cannot be created automatically and are subject to detail engineering by a specialist crossing engineer.

The following figure shows a screen shot of the PIEE Design menu within the AutoCAD environment:

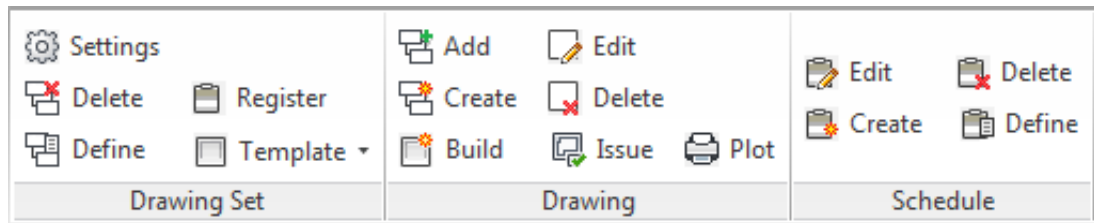


Figure 3.15 – PIEE AutoCAD Menu (PIEE Design Ribbon Tab)

Drawing Set Panel - contains PIEE functions related to Drawing Sets, includes: Define, Delete, Settings, Template and Register.

Drawing Set Panel – Template Drop Down List - Contains available methods for Drawing Set Templates (Create and Edit).

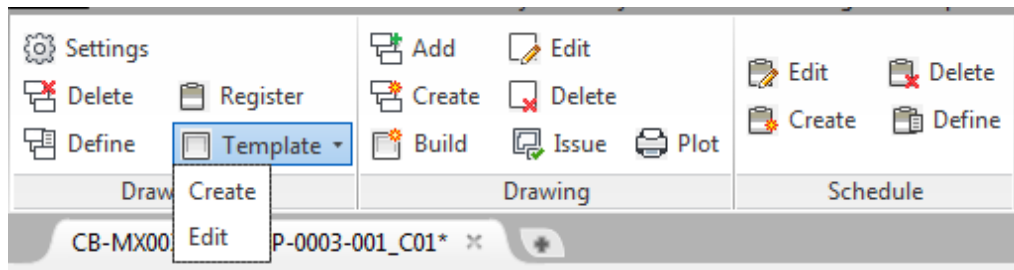


Figure 3.16 – Drawing Set Panel – Template Drop Down List

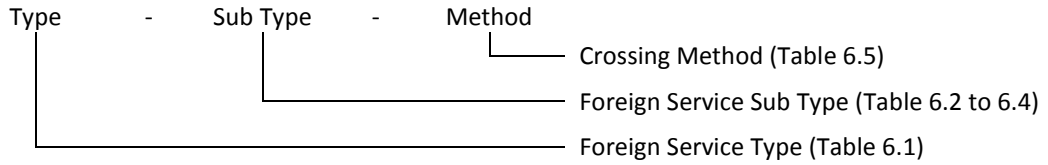
Drawing Panel - contains PIEE functions related to Drawings, includes: Build, Create, Add, Issue, Delete, Edit and Plot.

Schedule Panel - contains PIEE functions related to Schedules, includes: Create, Edit, Define and Delete.



4 Engineering

4.1 Foreign Service Codes



Type	Description
FXA	Foreign service (Above ground)
FXO	Foreign service (Overhead)
FXU	Foreign service (Underground)

Table 4.1 – Foreign Service Types

Type	Sub Type	Description
FXA	01	AG Pipe (Oil)
FXA	02	AG Pipe (Gas)
FXA	03	AG Pipe (Water)
FXA	04	AG Pipe (Unidentified)
FXA	05	AG Cable (Power)
FXA	06	AG Cable (Communication)
FXA	07	AG Cable (Fibre Optic)
FXA	08	AG Cable (Unidentified)

Table 4.2 – Foreign Service Sub Types (Above ground)

Type	Sub Type	Description
FXO	01	OH Cable (Power)
FXO	02	OH Cable (Communication)
FXO	03	OH Cable (Unidentified)

Table 4.3 – Foreign Service Sub Types (Overhead)



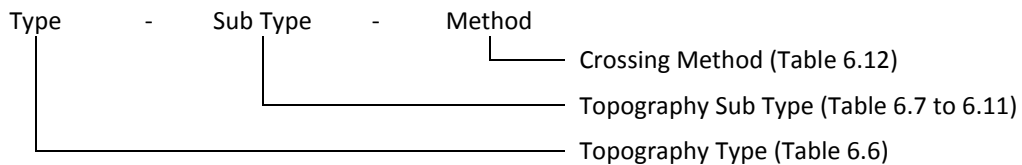
Type	Sub Type	Description
FXU	01	UG Pipe (Oil)
FXU	02	UG Pipe (Gas)
FXU	03	UG Pipe (Water)
FXU	04	UG Pipe (Unidentified)
FXU	05	UG Cable (Power)
FXU	06	UG Cable (Communication)
FXU	07	UG Cable (Fibre Optic)
FXU	08	UG Cable (Unidentified)

Table 4.4 – Foreign Service Sub Types (Underground)

Method	Description
U	Unclassified
O	Open cut
T	Trenchless (unspecified)
H	Horizontal directional drilling
A	Auger or thrust bored
G	Above ground

Table 4.5 – Crossing Methods

4.2 Topography Codes



Type	Description
PEX	Pedestrian (track)
RWX	Railway
SPX	Special e.g. seismic (project defined)
VEX	Road
WCX	Watercourse (dry or wet)

Table 4.6 – Topography Types

Type	Sub Type	Description
PEX	01	Track (Surfaced)
PEX	02	Track (Unsurfaced)

Table 4.7 – Topography Sub Types (Pedestrian)

Type	Sub Type	Description
RWX	01	Railway (Multi-line)
RWX	02	Railway (Single-line)
RWX	03	Railway (Narrow Gauge)
RWX	04	Railway (Disused)

Table 4.8 – Topography Sub Types (Railways)



Type	Sub Type	Description
SPX	01	Special e.g. seismic

Table 4.9 – Topography Sub Types (Special)

Type	Sub Type	Description
VEX	01	Multi Lane Highway
VEX	02	Major Road
VEX	03	Secondary Road
VEX	04	Minor Road
VEX	05	Stone Road
VEX	06	Earth Road

Table 4.10 – Topography Sub Types (Roads)

Type	Sub Type	Description
WCX	01	Major River
WCX	02	Minor River
WCX	03	Major Canal
WCX	04	Minor Canal
WCX	05	Gully
WCX	06	Stream
WCX	07	Ditch (Lined)
WCX	08	Ditch

Table 4.11 – Topography Sub Types (Watercourses)

Construction Method	Description
U	Unclassified
O	Open cut
T	Trenchless (unspecified)
H	Horizontal directional drilling
A	Auger or thrust bored
G	Above ground

Table 4.12 – Crossing Methods



5 Data Model Interoperability

The PIEE data model is designed to be independent of existing pipeline data models. This approach enables the greatest flexibility in interoperability with other data models, while insulating the PIEE data model from changes in external data models. In order to support interoperability, modules are created for the import and export of data from specific data models by version.

Currently the only import/export mapping provided within the PIEE is for PODS, based on a specific version in use by BP and known as the BP PODS Golden Build.

5.1 BP PODS GB (5.1.1.20130228.01)

The following tables provide the mapping requirements from PIEE to BP PODS Golden Build (version 5.1.1.20130228.01). Constants are quoted.

These are stored in a file (PODS 5.1.1.20130228.01.ini), for use by the PIEE for automating the creation of the PODS tables from the PIEE model for the specified PODS version.

5.1.1 Standard PODS Tables

PIEE Feature.Attribute	PODS Table.Attribute
PIEEModel.LogicalLineLoopEventID	LineLoop.EventID
CentreLine.AutocadHandle	LineLoop.TagID
	LineLoop.AlternateAssetID
PIEEModel.LogicalLineLoopEventID	LineLoop.OriginEventID
PIEEModel.CreatedBy	LineLoop.CreatedBy
PIEEModel.CreatedDate	LineLoop.CreatedDate
PIEEModel.CreatedDate	LineLoop.EffectiveFromDate
	LineLoop.EffectiveToDate
CentreLine.ModifiedDate	LineLoop.LastModified
CentreLine.ModifiedBy	LineLoop.ModifiedBy
'Current'	LineLoop.HistoricalState
	LineLoop.ProcessFlag
PIEEModel.Filename	LineLoop.SourceCL
	LineLoop.Remarks
	LineLoop.Description
	LineLoop.Hyperlink
	LineLoop.ProjectMaturityLevelCL
'Active'	LineLoop.OperationalStatus
PIEEModel.Name	LineLoop.LineName
	LineLoop.LineFunctionCL



PIEE Feature.Attribute	PODS Table.Attribute
PIEEModel.Product	LineLoop.ProductTypeCL
	LineLoop.ProductSubtypeCL
'N/A'	LineLoop.InterstateLF
	LineLoop.ParentUnitEventID
'N/A'	LineLoop.DesignLife
	LineLoop.AltDesignator
	LineLoop.AltLineName
	LineLoop.Designator

Table 5.1 – Attribute Mapping for PODS Table: LineLoop

PIEE Feature.Attribute	PODS Table.Attribute
CentreLine.CStationSeriesEventID or CentreLine.EStationSeriesEventID	StationSeries.EventID
CentreLine.AutocadHandle	StationSeries.TagID
	StationSeries.AlternateAssetID
CentreLine.CreatedBy	StationSeries.CreatedBy
CentreLine.CreatedDate	StationSeries.CreatedDate
CentreLine.CreatedDate	StationSeries.EffectiveFromDate
	StationSeries.EffectiveToDate
CentreLine.CStationSeriesEventID or CentreLine.EStationSeriesEventID	StationSeries.OriginEventID
CentreLine.ModifiedDate	StationSeries.LastModified
CentreLine.ModifiedBy	StationSeries.ModifiedBy
'Current'	StationSeries.HistoricalState
	StationSeries.ProcessFlag
PIEEModel.Filename	StationSeries.SourceCL
	StationSeries.Remarks
PIEEModel.Name	StationSeries.Description
	StationSeries.Hyperlink
	StationSeries.ProjectMaturityLevelCL
'Active'	StationSeries.OperationalStatus
\$2D1	StationSeries.BeginStation
\$2D2	StationSeries.EndStation
\$2D1	StationSeries.BeginMeasure
\$2D2	StationSeries.EndMeasure
'Continuous' or 'Engineering'	StationSeries.StationSeriesName
	StationSeries.SeriesOrder
	StationSeries.FromConnectionStationValue
	StationSeries.FromStationSeriesEventID



PIEE Feature.Attribute	PODS Table.Attribute
	StationSeries.ToConnectionStationValue
	StationSeries.ToStationSeriesEventID
PIEEModel.LogicalLineLoopEventID	StationSeries.LineLoopEventID
	StationSeries.ParentStationSeriesEventID
'Continuous' or 'Engineering'	StationSeries.RefMode

Table 5.2 – Attribute Mapping for PODS Table: StationSeries

PIEE Table.Attribute	PODS Table.Attribute
StationLine.EventID	ControlPoint.EventID
StationLine.AutocadHandle	ControlPoint.TagID
	ControlPoint.AlternateAssetID
StationLine.CreatedBy	ControlPoint.CreatedBy
StationLine.CreatedDate	ControlPoint.CreatedDate
StationLine.CreatedDate	ControlPoint.EffectiveFromDate
	ControlPoint.EffectiveToDate
StationLine.EventID	ControlPoint.OriginEventID
StationLine.ModifiedDate	ControlPoint.LastModified
StationLine.ModifiedBy	ControlPoint.ModifiedBy
'Current'	ControlPoint.HistoricalState
	ControlPoint.ProcessFlag
PIEEModel.FileName	ControlPoint.SourceCL
	ControlPoint.Remarks
	ControlPoint.Description
	ControlPoint.Hyperlink
	ControlPoint.ProjectMaturityLevelCL
'Active'	ControlPoint.OperationalStatus
	ControlPoint.SymbolRotation
	ControlPoint.CLXYEditResponse
	ControlPoint.CLStationEditResponse
	ControlPoint.CLZEditResponse
'Yes'	ControlPoint.CLControl
CentreLine.CStationSeriesEventID	ControlPoint.RouteEventID
CentreLine.EStationSeriesEventID	ControlPoint.SeriesEventID
\$2D1	ControlPoint.MeasureValue
\$2D1	ControlPoint.StationValue
\$X	ControlPoint.POINT_X
\$Y	ControlPoint.POINT_Y
\$Z	ControlPoint.POINT_Z



PIEE Table.Attribute	PODS Table.Attribute
\$Angle	ControlPoint.ControlPointAngle
\$Vtype	ControlPoint.ControlPointType
\$AngDesc	

Table 5.3 – Attribute Mapping for PODS Table: ControlPoint

PIEE Feature.Attribute	PODS Table.Attribute
IntersectionPoint.EventID	RoutingNote.EventID
IntersectionPoint.AutocadHandle	RoutingNote.TagID
	RoutingNote.AlternateAssetID
IntersectionPoint.CreatedBy	RoutingNote.CreatedBy
IntersectionPoint.CreatedDate	RoutingNote.CreatedDate
IntersectionPoint.CreatedDate	RoutingNote.EffectiveFromDate
	RoutingNote.EffectiveToDate
IntersectionPoint.EventID	RoutingNote.OriginEventID
IntersectionPoint.ModifiedDate	RoutingNote.LastModified
IntersectionPoint.ModifiedBy	RoutingNote.ModifiedBy
'Current'	RoutingNote.HistoricalState
	RoutingNote.ProcessFlag
PIEEModel.Filename	RoutingNote.SourceCL
	RoutingNote.Remarks
IntersectionPoint.Tag	RoutingNote.Description
	RoutingNote.Hyperlink
	RoutingNote.CLEditResponse
	RoutingNote.CLValidityTolerance
CentreLine.CStationSeriesEventID	RoutingNote.RouteEventID
	RoutingNote.VisualOffset
IntersectionPoint.2D1	RoutingNote.Measure
CentreLine.EStationSeriesEventID	RoutingNote.SeriesEventID
IntersectionPoint.2D1	RoutingNote.Station
'Active'	RoutingNote.Status
	RoutingNote.SymbolRotation
IntersectionPoint.X1	RoutingNote.POINT_X
IntersectionPoint.Y1	RoutingNote.POINT_Y
IntersectionPoint.Z1	RoutingNote.POINT_Z
IntersectionPoint.Angle	RoutingNote.ANGDegrees
	RoutingNote.ANGMinutes
	RoutingNote.ANGSeconds
	RoutingNote.BRGDegrees



PIEE Feature.Attribute	PODS Table.Attribute
	RoutingNote.BRGEasting
	RoutingNote.BRGMinutes
	RoutingNote.BRGNorthing
	RoutingNote.BRGSeconds
	RoutingNote.ScaledCL
IntersectionPoint.Tag	RoutingNote.SourceNumber
'IP'	RoutingNote.TypeCL

Table 5.4 – Attribute Mapping for PODS Table: RoutingNote

PIEE Feature.Attribute	PODS Table.Attribute
CrossingPoint.EventID	Road.EventID
CrossingPoint.AutocadHandle	Road.TagID
	Road.AlternateAssetID
CrossingPoint.CreatedBy	Road.CreatedBy
CrossingPoint.CreatedDate	Road.CreatedDate
CrossingPoint.CreatedDate	Road.EffectiveFromDate
	Road.EffectiveToDate
CrossingPoint.EventID	Road.OriginEventID
CrossingPoint.ModifiedDate	Road.LastModified
CrossingPoint.ModifiedBy	Road.ModifiedBy
'Current'	Road.HistoricalState
	Road.ProcessFlag
PIEEModel.FileName	Road.SourceCL
CrossingPoint.Description	Road.Remarks
CrossingPoint.Code	Road.Description
	Road.Hyperlink
	Road.CLEditResponse
	Road.CLValidityTolerance
CentreLine.CStationSeriesEventID	Road.RouteEventID
	Road.VisualOffset
CrossingPoint.2D1	Road.Measure
CentreLine.EStationSeriesEventID	Road.SeriesEventID
CrossingPoint.2D1	Road.Station
'Active'	Road.Status
	Road.SymbolRotation
CrossingPoint.X1	Road.POINT_X
CrossingPoint.Y1	Road.POINT_Y
CrossingPoint.Z1	Road.POINT_Z



PIEE Feature.Attribute	PODS Table.Attribute
	Road.CasingIndicatorLF
	Road.DirectionCL
CrossingPoint.Angle	Road.IntersectionAngle
	Road.ScaledCL
CrossingPoint.StandardDetail	Road.SourceNumber
	Road.SurfaceCL
CrossingPoint.Code	Road.TypeCL
CrossingPoint.Width	Road.Width

Table 5.5 – Attribute Mapping for PODS Table: Road

PIEE Feature.Attribute	PODS Table.Attribute
CrossingPoint..EventID	Railroad.EventID
CrossingPoint.AutocadHandle	Railroad.TagID
	Railroad.AlternateAssetID
CrossingPoint.CreatedBy	Railroad.CreatedBy
CrossingPoint.CreatedDate	Railroad.CreatedDate
CrossingPoint.CreatedDate	Railroad.EffectiveFromDate
	Railroad.EffectiveToDate
CrossingPoint..EventID	Railroad.OriginEventID
CrossingPoint.ModifiedDate	Railroad.LastModified
CrossingPoint.ModifiedBy	Railroad.ModifiedBy
'Current'	Railroad.HistoricalState
	Railroad.ProcessFlag
PIEEModel.FileName	Railroad.SourceCL
CrossingPoint.Description	Railroad.Remarks
CrossingPoint.Code	Railroad.Description
	Railroad.Hyperlink
	Railroad.CLEditResponse
	Railroad.CLValidityTolerance
CentreLine.CStationSeriesEventID	Railroad.RouteEventID
	Railroad.VisualOffset
CrossingPoint.2D1	Railroad.Measure
CentreLine.EStationSeriesEventID	Railroad.SeriesEventID
CrossingPoint.2D1	Railroad.Station
'Active'	Railroad.Status
	Railroad.SymbolRotation
CrossingPoint.X1	Railroad.POINT_X
CrossingPoint.Y1	Railroad.POINT_Y



PIEE Feature.Attribute	PODS Table.Attribute
CrossingPoint.Z1	Railroad.POINT_Z
	Railroad.CasingIndicatorLF
	Railroad.DirectionCL
CrossingPoint.Angle	Railroad.IntersectionAngle
	Railroad.OperatorCL
	Railroad.ScaledCL
CrossingPoint.StandardDetail	Railroad.SourceNumber
CrossingPoint.Code	Railroad.TypeCL
CrossingPoint.Width	Railroad.Width

Table 5.6 – Attribute Mapping for PODS Table: Railroad

PIEE Feature.Attribute	PODS Table.Attribute
CrossingPoint..EventID	Waterway.EventID
CrossingPoint.AutocadHandle	Waterway.TagID
	Waterway.AlternateAssetID
CrossingPoint.CreatedBy	Waterway.CreatedBy
CrossingPoint.CreatedDate	Waterway.CreatedDate
CrossingPoint.CreatedDate	Waterway.EffectiveFromDate
	Waterway.EffectiveToDate
CrossingPoint..EventID	Waterway.OriginEventID
CrossingPoint.ModifiedDate	Waterway.LastModified
CrossingPoint.ModifiedBy	Waterway.ModifiedBy
'Current'	Waterway.HistoricalState
	Waterway.ProcessFlag
PIEEModel.FileName	Waterway.SourceCL
CrossingPoint.Description	Waterway.Remarks
CrossingPoint.Code	Waterway.Description
	Waterway.Hyperlink
	Waterway.CLEditResponse
	Waterway.CLValidityTolerance
CentreLine.CStationSeriesEventID	Waterway.RouteEventID
	Waterway.VisualOffset
CrossingPoint.2D1	Waterway.Measure
CentreLine.EStationSeriesEventID	Waterway.SeriesEventID
CrossingPoint.2D1	Waterway.Station
'Active'	Waterway.Status
	Waterway.SymbolRotation
CrossingPoint.X1	Waterway.POINT_X



PIEE Feature.Attribute	PODS Table.Attribute
CrossingPoint.Y1	Waterway.POINT_Y
CrossingPoint.Z1	Waterway.POINT_Z
	Waterway.CasingIndicatorLF
	Waterway.DirectionCL
	Waterway.ExposureLF
CrossingPoint.Angle	Waterway.IntersectionAngle
	Waterway.ProtectedLF
	Waterway.ScaledCL
CrossingPoint.StandardDetail	Waterway.SourceNumber
CrossingPoint.Code	Waterway.TypeCL
	Waterway.WaterwayRemediationCL
CrossingPoint.Width	Waterway.Width

Table 5.7 – Attribute Mapping for PODS Table: Waterway

PIEE Feature.Attribute	PODS Table.Attribute
CrossingPoint..EventID	ForeignLineCrossing.EventID
CrossingPoint.AutocadHandle	ForeignLineCrossing.TagID
	ForeignLineCrossing.AlternateAssetID
CrossingPoint.CreatedBy	ForeignLineCrossing.CreatedBy
CrossingPoint.CreatedDate	ForeignLineCrossing.CreatedDate
CrossingPoint.CreatedDate	ForeignLineCrossing.EffectiveFromDate
	ForeignLineCrossing.EffectiveToDate
CrossingPoint..EventID	ForeignLineCrossing.OriginEventID
CrossingPoint.ModifiedDate	ForeignLineCrossing.LastModified
CrossingPoint.ModifiedBy	ForeignLineCrossing.ModifiedBy
'Current'	ForeignLineCrossing.HistoricalState
	ForeignLineCrossing.ProcessFlag
PIEEModel.FileName	ForeignLineCrossing.SourceCL
CrossingPoint.Description	ForeignLineCrossing.Remarks
CrossingPoint.Code	ForeignLineCrossing.Description
	ForeignLineCrossing.Hyperlink
	ForeignLineCrossing.CLEditResponse
	ForeignLineCrossing.CLValidityTolerance
CentreLine.CStationSeriesEventID	ForeignLineCrossing.RouteEventID
	ForeignLineCrossing.VisualOffset
CrossingPoint.2D1	ForeignLineCrossing.Measure
CentreLine.EStationSeriesEventID	ForeignLineCrossing.SeriesEventID
CrossingPoint.2D1	ForeignLineCrossing.Station



PIEE Feature.Attribute	PODS Table.Attribute
'Active'	ForeignLineCrossing.Status
	ForeignLineCrossing.SymbolRotation
CrossingPoint.X1	ForeignLineCrossing.POINT_X
CrossingPoint.Y1	ForeignLineCrossing.POINT_Y
CrossingPoint.Z1	ForeignLineCrossing.POINT_Z
	ForeignLineCrossing.ActualClearance
	ForeignLineCrossing.ActualCrossingAngle
	ForeignLineCrossing.ActualCrossingCenEasting
	ForeignLineCrossing.ActualCrossingCenNorthing
	ForeignLineCrossing.ActualCrossingLength
	ForeignLineCrossing.ActualCrossingWidth
	ForeignLineCrossing.AdjacentBuriedUtilityCL
	ForeignLineCrossing.BuriedUtilityCL
	ForeignLineCrossing.CrossingBelowGroundLF
	ForeignLineCrossing.CrossingDate
	ForeignLineCrossing.CrossingName
CrossingPoint.Angle	ForeignLineCrossing.CrossingOrientation
	ForeignLineCrossing.DirectionCL
	ForeignLineCrossing.ForeignBondLF
CrossingPoint.Width	ForeignLineCrossing.ForeignDiameter
CrossingPoint.BelowGround	ForeignLineCrossing.LineBelowGroundLF
CrossingPoint.Height	ForeignLineCrossing.LineClearance
CrossingPoint.Description	ForeignLineCrossing.MaterialCL
CrossingPoint.Height	ForeignLineCrossing.MaxHeight
	ForeignLineCrossing.OwnerCL
	ForeignLineCrossing.ScaledCL
CrossingPoint.StandardDetail	ForeignLineCrossing.SourceNumber
CrossingPoint.Code	ForeignLineCrossing.TypeCL

Table 5.8 – Attribute Mapping for PODS Table: ForeignLineCrossing

PIEE Feature.Attribute	PODS Table.Attribute
DOTSegment.EventID	DOTClass.EventID
DOTSegment.AutocadHandle	DOTClass.TagID
	DOTClass.AlternateAssetID
DOTSegment.CreatedBy	DOTClass.CreatedBy
DOTSegment.CreatedDate	DOTClass.CreatedDate
DOTSegment.CreatedDate	DOTClass.EffectiveFromDate
	DOTClass.EffectiveToDate



PIEE Feature.Attribute	PODS Table.Attribute
DOTSegment.EventID	DOTClass.OriginEventID
DOTSegment.ModifiedDate	DOTClass.LastModified
DOTSegment.ModifiedBy	DOTClass.ModifiedBy
'Current'	DOTClass.HistoricalState
	DOTClass.ProcessFlag
'ASME 31.8'	DOTClass.SourceCL
DOTSegment.Dwellings	DOTClass.Remarks
	DOTClass.Description
	DOTClass.Hyperlink
	DOTClass.CLEditResponse
	DOTClass.CLValidityTolerance
CentreLine.CStationSeriesEventID	DOTClass.RouteEventID
	DOTClass.VisualOffset
DOTSegment.2D1	DOTClass.BeginMeasure
DOTSegment.2D2	DOTClass.EndMeasure
CentreLine.EStationSeriesEventID	DOTClass.BeginSeriesEventID
CentreLine.EStationSeriesEventID	DOTClass.EndSeriesEventID
DOTSegment.2D1	DOTClass.BeginStation
DOTSegment.2D2	DOTClass.EndStation
	DOTClass.Status
	DOTClass.GroupEventID
	DOTClass.IntersectionMethodCL
	DOTClass.RunID
DOTSegment.Class	DOTClass.RatingCL
DOTSegment.Class	DOTClass.DesignCL
	DOTClass.MethodCL
DOTSegment.ModifiedDate	DOTClass.DeterminationDate

Table 5.9 – Attribute Mapping for PODS Table: DOTClass

PIEE Feature.Attribute	PODS Table.Attribute
Reference.EventID	HCABoundary.EventID
Reference.AutocadHandle	HCABoundary.TagID
	HCABoundary.AlternateAssetID
Reference.CreatedBy	HCABoundary.CreatedBy
Reference.CreatedDate	HCABoundary.CreatedDate
Reference.CreatedDate	HCABoundary.EffectiveFromDate
	HCABoundary.EffectiveToDate
Reference.EventID	HCABoundary.OriginEventID



PIEE Feature.Attribute	PODS Table.Attribute
Reference.ModifiedDate	HCABoundary.LastModified
Reference.ModifiedBy	HCABoundary.ModifiedBy
'Current'	HCABoundary.HistoricalState
	HCABoundary.ProcessFlag
	HCABoundary.SourceCL
	HCABoundary.Remarks
	HCABoundary.Description
	HCABoundary.Hyperlink
	HCABoundary.CLEditResponse
	HCABoundary.CLValidityTolerance
CentreLine.CStationSeriesEventID	HCABoundary.RouteEventID
	HCABoundary.VisualOffset
Reference.2D1	HCABoundary.BeginMeasure
Reference.2D2	HCABoundary.EndMeasure
CentreLine.EStationSeriesEventID	HCABoundary.BeginSeriesEventID
CentreLine.EStationSeriesEventID	HCABoundary.EndSeriesEventID
Reference.2D1	HCABoundary.BeginStation
Reference.2D2	HCABoundary.EndStation
	HCABoundary.Status
	HCABoundary.GroupEventID
Reference.Number	HCABoundary.TypeCL
	HCABoundary.DeterminationDate

Table 5.10 – Attribute Mapping for PODS Table: HCABoundary

PIEE Feature.Attribute	PODS Table.Attribute
PipeSegment.EventID	PipeSegment.EventID
PipeSegment.AutocadHandle	PipeSegment.TagID
	PipeSegment.AlternateAssetID
PipeSegment.CreatedBy	PipeSegment.CreatedBy
PipeSegment.CreatedDate	PipeSegment.CreatedDate
PipeSegment.CreatedDate	PipeSegment.EffectiveFromDate
	PipeSegment.EffectiveToDate
PipeSegment.EventID	PipeSegment.OriginEventID
PipeSegment.ModifiedDate	PipeSegment.LastModified
PipeSegment.ModifiedBy	PipeSegment.ModifiedBy
'Current'	PipeSegment.HistoricalState
	PipeSegment.ProcessFlag
	PipeSegment.SourceCL



PIEE Feature.Attribute	PODS Table.Attribute
	PipeSegment.Remarks
	PipeSegment.Description
	PipeSegment.Hyperlink
	PipeSegment.ProjectMaturityLevelCL
PipeSegment.CreatedDate	PipeSegment.InServiceDate
	PipeSegment.InstallationDate
'Active'	PipeSegment.OperationalStatus
	PipeSegment.SiteEventID
'95.5'	PipeSegment.DesignPressure
'74'	PipeSegment.MaximumDesignTemperature
'-1'	PipeSegment.MinimumDesignTemperature
	PipeSegment.ManufacturedDate
PipeSegment.2D1	PipeSegment.BeginMeasure
PipeSegment.2D2	PipeSegment.EndMeasure
CentreLine.EStationSeriesEventID	PipeSegment.BeginSeriesEventID
CentreLine.EStationSeriesEventID	PipeSegment.EndSeriesEventID
PipeSegment.2D1	PipeSegment.BeginStation
PipeSegment.2D2	PipeSegment.EndStation
	PipeSegment.GroupEventID
CentreLine.CStationSeriesEventID	PipeSegment.RouteEventID
	PipeSegment.VisualOffset
PipeSegment.Type	PipeSegment.PipeSegmentTypeCL
	PipeSegment.AboveGroundPipeLF
	PipeSegment.CarrierPipeEventID
	PipeSegment.CarrierPipeLF
	PipeSegment.DepartureAngle
	PipeSegment.DepthAtTouchdown
PipeSegment.DesignFactor	PipeSegment.DesignFactor
	PipeSegment.DateInstalled
	PipeSegment.DateManufactured
'No'	PipeSegment.FlexiblePipeLF
PipeSegment.Grade	PipeSegment.GradeCL
	PipeSegment.HardSpotAssessmentLF
	PipeSegment.HardSpotPresenceLF
	PipeSegment.HeatNumber
	PipeSegment.InstallationContractorCL
'Welded'	PipeSegment.JointTypeCL
'Submerged Arc Weld'	PipeSegment.LongSeamCL



PIEE Feature.Attribute	PODS Table.Attribute
	PipeSegment.ManufacturerCL
'API 5L X7 PSL2'	PipeSegment.MaterialCL
	PipeSegment.MillLocationCL
	PipeSegment.MillTestPressure
PipeSegment.OutsideDiameter	PipeSegment.NominalDiameterCL
PipeSegment.OutsideDiameter	PipeSegment.NominalInternalDiameter
	PipeSegment.NominalInterDiameterOutletCL
	PipeSegment.NominalPressureRating
PipeSegment.WallThickness	PipeSegment.NominalWallThicknessCL
	PipeSegment.NominalWallThicknessOutletCL
	PipeSegment.PointFeatureEventID
	PipeSegment.PointFeatureTableName
	PipeSegment.PartNumber
	PipeSegment.PipeInPipeInnerOuterCL
	PipeSegment.RegulatedSegmentLF
PipeSegment.ID	PipeSegment.SegmentID
	PipeSegment.SerialNumber
'485'	PipeSegment.SMYS
	PipeSegment.SMYSCL
'ASME B31.8:21'	PipeSegment.SpecificationCL
	PipeSegment.SpecificationEventID
	PipeSegment.SpecificationTableName
	PipeSegment.Toughness
	PipeSegment.WrinkleBendLF

Table 5.11 – Attribute Mapping for PODS Table: PipeSegment

PIEE Feature.Attribute	PODS Table.Attribute
PipeSegment..EventID	PipeBend.EventID
PipeSegment.AutocadHandle	PipeBend.TagID
	PipeBend.AlternateAssetID
PipeSegment.CreatedBy	PipeBend.CreatedBy
PipeSegment.CreatedDate	PipeBend.CreatedDate
PipeSegment.CreatedDate	PipeBend.EffectiveFromDate
	PipeBend.EffectiveToDate
PipeSegment.EventID	PipeBend.OriginEventID
PipeSegment.ModifiedDate	PipeBend.LastModified
PipeSegment.ModifiedBy	PipeBend.ModifiedBy
'Current'	PipeBend.HistoricalState
	PipeBend.ProcessFlag



PIEE Feature.Attribute	PODS Table.Attribute
	PipeBend.SourceCL
	PipeBend.Remarks
	PipeBend.Description
	PipeBend.Hyperlink
	PipeBend.ProjectMaturityLevelCL
PipeSegment.CreatedDate	PipeBend.InServiceDate
	PipeBend.InstallationDate
'Active'	PipeBend.OperationalStatus
	PipeBend.SiteEventID
'95.5'	PipeBend.DesignPressure
'74'	PipeBend.MaximumDesignTemperature
'-1'	PipeBend.MinimumDesignTemperature
	PipeBend.ManufacturedDate
PipeSegment.2D1	PipeBend.Measure
CentreLine.EStationSeriesEventID	PipeBend.SeriesEventID
PipeSegment.2D1	PipeBend.Station
	PipeBend.SymbolRotation
PipeSegment.X1	PipeBend.POINT_X
PipeSegment.Y1	PipeBend.POINT_Y
	PipeBend.POINT_Z
CentreLine.CStationSeriesEventID	PipeBend.RouteEventID
	PipeBend.VisualOffset
'Induction Bend'	PipeBend.TypeCL
	PipeBend.TechniqueCL
PipeSegment.Radius	PipeBend.BendRadius
PipeSegment.Angle	PipeBend.HorizAngle
	PipeBend.VertAngle
	PipeBend.FabricatorNameCL

Table 5.12 – Attribute Mapping for PODS Table: PipeBend

PIEE Feature.Attribute	PODS Table.Attribute
CPLocation.EventID	JunctionBox.EventID
CPLocation.AutocadHandle	JunctionBox.TagID
	JunctionBox.AlternateAssetID
CPLocation.CreatedBy	JunctionBox.CreatedBy
CPLocation.CreatedDate	JunctionBox.CreatedDate
CPLocation.CreatedDate	JunctionBox.EffectiveFromDate
	JunctionBox.EffectiveToDate
CPLocation.EventID	JunctionBox.OriginEventID
CPLocation.ModifiedDate	JunctionBox.LastModified
CPLocation.ModifiedBy	JunctionBox.ModifiedBy



PIEE Feature.Attribute	PODS Table.Attribute
'Current'	JunctionBox.HistoricalState
	JunctionBox.ProcessFlag
CPLocation.Tag	JunctionBox.SourceCL
	JunctionBox.Remarks
CPLocation.2D1	JunctionBox.Description
	JunctionBox.Hyperlink
	JunctionBox.ProjectMaturityLevelCL
CPLocation.CreatedDate	JunctionBox.InServiceDate
	JunctionBox.InstallationDate
'Active'	JunctionBox.OperationalStatus
	JunctionBox.SiteEventID
	JunctionBox.DesignPressure
	JunctionBox.MaximumDesignTemperature
	JunctionBox.MinimumDesignTemperature
	JunctionBox.ManufacturedDate
	JunctionBox.SymbolRotation
CPLocation.X1	JunctionBox.POINT_X
CPLocation.Y1	JunctionBox.POINT_Y
	JunctionBox.POINT_Z
	JunctionBox.AnodeConnectedLF
	JunctionBox.BoxSize
	JunctionBox.DateInstalled
	JunctionBox.GroundBedConnectedLF
	JunctionBox.Name
	JunctionBox.NEMARating
	JunctionBox.NumberOfWires
	JunctionBox.Pole
	JunctionBox.RectifierConnectedLF
'Yes'	JunctionBox.Weatherproof

Table 5.13 – Attribute Mapping for PODS Table: JunctionBox

PIEE Feature.Attribute	PODS Table.Attribute
Marker.EventID	Marker.EventID
Marker.AutocadHandle	Marker.TagID
	Marker.AlternateAssetID
Marker.CreatedBy	Marker.CreatedBy
Marker.CreatedDate	Marker.CreatedDate
Marker.CreatedDate	Marker.EffectiveFromDate



PIEE Feature.Attribute	PODS Table.Attribute
	Marker.EffectiveToDate
Marker.EventID	Marker.OriginEventID
Marker.ModifiedDate	Marker.LastModified
Marker.ModifiedBy	Marker.ModifiedBy
'Current'	Marker.HistoricalState
	Marker.ProcessFlag
Marker.Tag	Marker.SourceCL
	Marker.Remarks
	Marker.Description
	Marker.Hyperlink
	Marker.TagID
	Marker.ProjectMaturityLevelCL
Marker.CreatedDate	Marker.InServiceDate
	Marker.InstallationDate
'Active'	Marker.OperationalStatus
	Marker.DesignPressure
	Marker.MaximumDesignTemperature
	Marker.MinimumDesignTemperature
	Marker.ManufacturedDate
	Marker.SiteEventID
	Marker.SymbolRotation
Marker.X1	Marker.POINT_X
Marker.Y1	Marker.POINT_Y
	Marker.POINT_Z
CentreLine.CStationSeriesEventID	Marker.RouteEventID
CentreLine.EStationSeriesEventID	Marker.SeriesEventID
Marker.2D1	Marker.Station
Marker.2D1	Marker.Measure
	Marker.DateInstalled
Marker.2D1	Marker.MarkerNumber
Marker.Type	Marker.MarkerTypeCL
	Marker.SignTypeCL

Table 5.14 – Attribute Mapping for PODS Table: Marker

PIEE Feature.Attribute	PODS Table.Attribute
PipeSegment.EventID	Valve.EventID
PipeSegment.AutocadHandle	Valve.TagID
	Valve.AlternateAssetID



PIEE Feature.Attribute	PODS Table.Attribute
PipeSegment.CreatedBy	Valve.CreatedBy
PipeSegment.CreatedDate	Valve.CreatedDate
PipeSegment.CreatedDate	Valve.EffectiveFromDate
	Valve.EffectiveToDate
PipeSegment.EventID	Valve.OriginEventID
PipeSegment.ModifiedDate	Valve.LastModified
PipeSegment.ModifiedBy	Valve.ModifiedBy
'Current'	Valve.HistoricalState
	Valve.ProcessFlag
	Valve.SourceCL
	Valve.Remarks
	Valve.Description
	Valve.Hyperlink
	Valve.ProjectMaturityLevelCL
PipeSegment.CreatedDate	Valve.InServiceDate
	Valve.InstallationDate
'Active'	Valve.OperationalStatus
	Valve.SiteEventID
	Valve.DesignPressure
	Valve.MaximumDesignTemperature
	Valve.MinimumDesignTemperature
	Valve.ManufacturedDate
PipeSegment.2D1	Valve.Measure
CentreLine.EStationSeriesEventID	Valve.SeriesEventID
PipeSegment.2D1	Valve.Station
	Valve.SymbolRotation
PipeSegment.X1	Valve.POINT_X
PipeSegment.Y1	Valve.POINT_Y
	Valve.POINT_Z
CentreLine.CStationSeriesEventID	Valve.RouteEventID
	Valve.VisualOffset
	Valve.ActuationCL
	Valve.DateInstalled
	Valve.DateManufactured
	Valve.FunctionCL
	Valve.JointTypeCL
	Valve.ManufacturerCL
	Valve.MaterialCL



PIEE Feature.Attribute	PODS Table.Attribute
	Valve.MillTestPressure
	Valve.Model
PipeSegment.Tag	Valve.Name
	Valve.NominalDiameterInletCL
	Valve.NominalDiameterOutletCL
	Valve.NominalPressureRating
	Valve.NominalPressureRatingInlet
	Valve.NominalPressureRatingOutlet
	Valve.RatingCL
	Valve.SerialNumber
	Valve.SpecificationCL
	Valve.TypeCL
	Valve.ValveIdentifier

Table 5.15 – Attribute Mapping for PODS Table: Valve

PIEE Feature.Attribute	PODS Table.Attribute
Cover.EventID	DepthOfCover.EventID
Cover.AutocadHandle	DepthOfCover.TagID
	DepthOfCover.AlternateAssetID
Cover.CreatedBy	DepthOfCover.CreatedBy
Cover.CreatedDate	DepthOfCover.CreatedDate
Cover.CreatedDate	DepthOfCover.EffectiveFromDate
	DepthOfCover.EffectiveToDate
Cover.EventID	DepthOfCover.OriginEventID
Cover.ModifiedDate	DepthOfCover.LastModified
Cover.CoverModifiedBy	DepthOfCover.ModifiedBy
'Current'	DepthOfCover.HistoricalState
	DepthOfCover.ProcessFlag
'ASME 31.8'	DepthOfCover.SourceCL
	DepthOfCover.Remarks
	DepthOfCover.Description
	DepthOfCover.Hyperlink
	DepthOfCover.CLEditResponse
	DepthOfCover.CLValidityTolerance
CentreLine.CStationSeriesEventID	DepthOfCover.RouteEventID
	DepthOfCover.VisualOffset
Cover.2D1	DepthOfCover.BeginMeasure
Cover.2D2	DepthOfCover.EndMeasure



PIEE Feature.Attribute	PODS Table.Attribute
CentreLine.EStationSeriesEventID	DepthOfCover.BeginSeriesEventID
CentreLine.EStationSeriesEventID	DepthOfCover.EndSeriesEventID
Cover.2D1	DepthOfCover.BeginStation
Cover.2D2	DepthOfCover.EndStation
	DepthOfCover.Status
	DepthOfCover.GroupEventID
	DepthOfCover.TypeCL
Cover.CreatedDate	DepthOfCover.DeterminationDate
	DepthOfCover.DeterminationMethodCL
	DepthOfCover.GroundElevation
	DepthOfCover.PipeElevationTop
	DepthOfCover.WaterElevation
	DepthOfCover.ElevationUOM
Cover.Cover	DepthOfCover.DepthOfBurial

Table 5.16 – Attribute Mapping for PODS Table: DepthOfCover

PIEE Feature.Attribute	PODS Table.Attribute
ConcreteCoating.EventID	Coating.EventID
ConcreteCoating.AutocadHandle	Coating.TagID
	Coating.AlternateAssetID
ConcreteCoating.CreatedBy	Coating.CreatedBy
ConcreteCoating.CreatedDate	Coating.CreatedDate
ConcreteCoating.CreatedDate	Coating.EffectiveFromDate
	Coating.EffectiveToDate
ConcreteCoating.EventID	Coating.OriginEventID
ConcreteCoating.ModifiedDate	Coating.LastModified
ConcreteCoating.ModifiedBy	Coating.ModifiedBy
'Current'	Coating.HistoricalState
	Coating.ProcessFlag
	Coating.SourceCL
	Coating.Remarks
	Coating.Description
	Coating.Hyperlink
	Coating.ProjectMaturityLevelCL
ConcreteCoating.CreatedDate	Coating.InServiceDate
	Coating.InstallationDate
'Active'	Coating.OperationalStatus
	Coating.SiteEventID



PIEE Feature.Attribute	PODS Table.Attribute
	Coating.DesignPressure
	Coating.MaximumDesignTemperature
	Coating.MinimumDesignTemperature
	Coating.ManufacturedDate
ConcreteCoating.2D1	Coating.BeginMeasure
ConcreteCoating.2D2	Coating.EndMeasure
CentreLine.EStationSeriesEventID	Coating.BeginSeriesEventID
CentreLine.EStationSeriesEventID	Coating.EndSeriesEventID
ConcreteCoating.2D1	Coating.BeginStation
ConcreteCoating.2D2	Coating.EndStation
	Coating.GroupEventID
CentreLine.CStationSeriesEventID	Coating.RouteEventID
	Coating.VisualOffset
	Coating.TypeCL
	Coating.SubtypeCL
	Coating.CoatingLocationCL
	Coating.CoatingManufacturerCL
ConcreteCoating.Description	Coating.CoatingMaterialCL
	Coating.ProductName
	Coating.CoatingApplicatorCL
	Coating.WhereCoatingAppliedCL
	Coating.DateApplied
	Coating.InsulationTypeCL
	Coating.JointCoatingMaterialCL
	Coating.Thickness
	Coating.ThicknessTolerance
	Coating.ThicknessUOM
	Coating.Density
	Coating.HeatCapacity
	Coating.ApplicationInspectionDate
	Coating.ThermalConductivity

Table 5.17 – Attribute Mapping for PODS Table: Coating

PIEE Feature.Attribute	PODS Table.Attribute
ConcreteSlab.EventID	ConcreteSlab.EventID
ConcreteSlab.AutocadHandle	ConcreteSlab.TagID
	ConcreteSlab.AlternateAssetID
ConcreteSlab.CreatedBy	ConcreteSlab.CreatedBy



PIEE Feature.Attribute	PODS Table.Attribute
ConcreteSlab.CreatedDate	ConcreteSlab.CreatedDate
ConcreteSlab.CreatedDate	ConcreteSlab.EffectiveFromDate
	ConcreteSlab.EffectiveToDate
ConcreteSlab.EventID	ConcreteSlab.OriginEventID
ConcreteSlab.ModifiedDate	ConcreteSlab.LastModified
ConcreteSlab.ModifiedBy	ConcreteSlab.ModifiedBy
'Current'	ConcreteSlab.HistoricalState
	ConcreteSlab.ProcessFlag
	ConcreteSlab.SourceCL
	ConcreteSlab.Remarks
	ConcreteSlab.Description
	ConcreteSlab.Hyperlink
	ConcreteSlab.ProjectMaturityLevelCL
ConcreteSlab.CreatedDate	ConcreteSlab.InServiceDate
	ConcreteSlab.InstallationDate
'Active'	ConcreteSlab.OperationalStatus
	ConcreteSlab.SiteEventID
	ConcreteSlab.DesignPressure
	ConcreteSlab.MaximumDesignTemperature
	ConcreteSlab.MinimumDesignTemperature
	ConcreteSlab.ManufacturedDate
ConcreteSlab.2D1	ConcreteSlab.BeginMeasure
ConcreteSlab.2D2	ConcreteSlab.EndMeasure
CentreLine.EStationSeriesEventID	ConcreteSlab.BeginSeriesEventID
CentreLine.EStationSeriesEventID	ConcreteSlab.EndSeriesEventID
ConcreteSlab.2D1	ConcreteSlab.BeginStation
ConcreteSlab.2D2	ConcreteSlab.EndStation
	ConcreteSlab.GroupEventID
CentreLine.CStationSeriesEventID	ConcreteSlab.RouteEventID
	ConcreteSlab.VisualOffset
	ConcreteSlab.Name
	ConcreteSlab.Weight
'15'	ConcreteSlab.Thickness

Table 5.18 – Attribute Mapping for PODS Table: ConcreteSlab



5.1.2 PODS PIEE Sub-Model Tables

PIEE Feature.Attribute	PODS Table.Attribute
Label.EventID	Label-PIEE.EventID
Label.AutocadHandle	Label-PIEE.TagID
	Label-PIEE.AlternateAssetID
Label.CreatedBy	Label-PIEE.CreatedBy
Label.CreatedDate	Label-PIEE.CreatedDate
Label.CreatedDate	Label-PIEE.EffectiveFromDate
	Label-PIEE.EffectiveToDate
Label.EventID	Label-PIEE.OriginEventID
Label.ModifiedDate	Label-PIEE.LastModified
Label.ModifiedBy	Label-PIEE.ModifiedBy
'Current'	Label-PIEE.HistoricalState
	Label-PIEE.LabelType
Label.Value	Label-PIEE.LabelValue
Label.X1	Label-PIEE.POINT_X
Label..Y1	Label-PIEE.POINT_Y

Table 5.19 – Attribute Mapping for PODS Table: PIEE.Label



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Appendices



Appendix A – PEE Automated Sample Drawings

I confirm that if the submission is based upon work that has been sponsored or supported by an agency or organisation that I have fulfilled any right of review or other obligations required by such contract or agreement.



Appendix A1 – Route Map



[Replace Page]



Appendix A2 – Strip Map (Type A)



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Appendix A3 – Strip Map (Type B)



[Replace Page]



Appendix A4 – Engineering Alignment Sheet



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Appendix A5 – Reinstatement Assessment Drawing



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Appendix A6 – Environmental Alignment Sheet



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Appendix A7 – Cadastral Alignment Sheet



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Appendix A8 – Preliminary as-built Alignment Sheet



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Appendix A9 – Final as-built Alignment Sheet



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Appendix A10 – Standard Crossing Drawing



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Appendix F – Code Sample (PIEE_PODS-Export)

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```

;*****
; Module:      PIEE_PODS-Export
; Status:     Issued
; Revision:    01.001
; Description: PIEE PODS Export Function Library
; Written By:  Keith Winning
;
; -----
; Function Listing
; -----
;
; p_PODS-Export           Exports the PIEE model data to PODS tables
; p_PODS-ExportCheckVariables Checks that the fixed variables required for the
;                          table are present
; p_PODS-AddValue        Builds the table entry for an individual record
; p_PODS-ExportLineLoop  Builds the PODS LineLoop table
; p_PODS-ExportStationSeries Builds the PODS StationSeries table
; p_PODS-ExportControlPoint Builds the PODS ControlPoint table
; =====
; Declare Functions
; -----
;
; Function:    p_PODS-Export
; Purpose:     Exports the PIEE model data to PODS tables
; Syntax:      (p_PODS-Export)
; Inputs:      None
; Returns:     None
; References:  acLib, dosLib
; Notes:      1. The Table/Field mapping is defined in the PODS Table Mapping.ini
;              file which should reside in the PODS sub folder of the project.
;              2. The order that the tables are created is critical as data is defined
;                 during table creation which subsequent tables depend on.
; -----
(defun p_PODS-Export ( / t1 path ifile elst handle 2d2 date cdata tk rk t2 tt)
  (Err_FunctionList "p_PODS-Export")
  (setq path (strcat (getvar "dwgprefix") "PODS\\"))
  (setq ifile (strcat path "PODS Table Mapping.ini"))
  (if (= (findfile ifile) NIL)
    (alert "Error Unable to find 'PODS Table Mapping.ini' file")
    (progn
      (setq t1 (Dtm_SystemTime "HH:MM:SS"))
      (setq elst (IPD_Rou-GetRoute "3D"))
      (setq handle (cdr (assoc 5 (entget (car elst)))))
      (setq 2d2 (rtos (cdr (assoc "2D Length" (ply_info elst))) 2 3))
      (setq date (Dtm_SystemDate "DD/MM/YYYY"))
      (setq cdata (list (cons "$Route3DHandle" handle)))
      (setq cdata (cons (cons "$2D1" "0.0") cdata))
      (setq cdata (cons (cons "$2D2" 2d2) cdata))
      (setq cdata (cons (cons "path" path) cdata))
      (setq cdata (cons (cons "ifile" ifile) cdata))
      (setq cdata
        (cons (cons "$ModelFile" (vl-filename-base (getvar "dwgname"))) cdata)
      ) ;setq
      (setq cdata (cons (cons "$Username" (dos_username)) cdata))
      (setq cdata (cons (cons "$Date" date) cdata))
      (setq cdata
        (cons (cons "$DateTime" (strcat date " " (Dtm_SystemTime "HH:MM"))) cdata)
      ) ;setq
      (setq cdata (cons (cons "TableCount" 0) cdata))
      (setq cdata (cons (cons "RecordCount" 0) cdata))
      (setq cdata (p_PODS-ExportLineLoop cdata))
      (setq cdata (p_PODS-ExportStationSeries cdata))
      (setq cdata (p_PODS-ExportControlPoint elst cdata))
      (setq cdata (p_PODS-ExportRoutingNote cdata))
      (setq cdata (p_PODS-ExportRoad cdata))
      (setq cdata (p_PODS-ExportRailroad cdata))
      (setq cdata (p_PODS-ExportWaterway cdata))
      (setq cdata (p_PODS-ExportForeignLineCrossing cdata))
      (setq cdata (p_PODS-ExportHCACASegment cdata))
      (setq cdata (p_PODS-ExportHCABoundary cdata))
      (setq cdata (p_PODS-ExportPipeSegment cdata))
      (setq cdata (p_PODS-ExportElbow cdata))
      (setq cdata (p_PODS-ExportConcreteSlab cdata))
      (setq cdata (p_PODS-ExportCoating cdata))
      (setq cdata (p_PODS-ExportJunctionBox cdata))
      (setq cdata (p_PODS-ExportMarker cdata))
    )
  )

```

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```

(setq cdata (p_PODS-ExportValve cdata))
(setq tk (itoa (cdr (assoc "TableCount" cdata))))
(setq rk (itoa (cdr (assoc "RecordCount" cdata))))
(setq t2 (Dtm_SystemTime "HH:MM:SS"))
(setq t1 (Lst_String->List t1 ":"))
(setq t2 (Lst_String->List t2 ":"))
(setq t1
  (+ (* (atoi (nth 0 t1)) 360) (* (atoi (nth 1 t1)) 60) (atoi (nth 2 t1)))
) ;setq
(setq t2
  (+ (* (atoi (nth 0 t2)) 360) (* (atoi (nth 1 t2)) 60) (atoi (nth 2 t2)))
) ;setq
(setq tt (itoa (- t2 t1)))
) ;progn
) ;if
(Err_FunctionList NIL)
(princ
  (strcat
    "\n\t" tk " PODS tables with " rk " attributes created in " tt " seconds."
  ) ;strcat
) ;princ
(princ)
) ;defun
; -----
; Function:    p_PODS-ExportCheckVariables
; Purpose:    Checks that the fixed variables required for the table are present
; Syntax:    (p_PODS-ExportCheckVariables rtdata cdata flst)
; Inputs:    Rtdata (List), cdata (List), flst (List)
; Returns:    T or NIL
; References: acLib
; Notes:    1. The Rtdata list is a list of variables that are determined at run
;           time and are excluded from the check.
;           2. The Cdata list is the list of cons pair values which are created
;           during the export process.
;           3. The Flst list contains the table definition as defined in the PODS
;           Table Mapping.ini file.
; -----
(defun p_PODS-ExportCheckVariables (rtdata cdata flst / res f cdatachk flstchk)
  (Err_FunctionList "p_PODS-ExportCheckVariables")
  (Err_CheckArguments
    (list rtdata cdata flst) (list (list "LIST" "NIL") "LIST" "LIST")
  ) ;Err_CheckArguments
  (setq res T)
  (foreach f cdata (setq cdatachk (cons (car f) cdatachk)))
  (foreach f flst (setq flstchk (cons (cdr f) flstchk)))
  (foreach f flstchk
    (if (= (Utl_Member f rtdata) NIL) ;Not run time variable
      (if (= (substr f 1 1) "$") ;Variable not string
        (if (= (Utl_Member f cdatachk) NIL) ; Missing fixed variable
          (setq res NIL)
        ) ;if
      ) ;if
    ) ;if
  ) ;foreach
  (Err_FunctionList NIL)
  (setq res res)
) ;defun
; -----
; Function:    p_PODS-SetVars
; Purpose:    Sets the variable values for the table
; Syntax:    (p_PODS-SetVars rtdata cdata flst)
; Inputs:    Rtdata (List), cdata (List), flst (List)
; Returns:    T or NIL
; References: acLib
; Notes:    1. The Rtdata list is a list of variables that are determined at run
;           time and are excluded from the check.
;           2. The Cdata list is the list of cons pair values which are created
;           during the export process.
;           3. The Flst list contains the table definition as defined in the PODS
;           Table Mapping.ini file.
; -----
(defun p_PODS-SetVars (rtdata cdata flst / res s setting val cval)
  (Err_FunctionList "p_PODS-SetVars")
  (Err_CheckArguments

```

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```

    (list rtdata cdata flst) (list (list "LIST" "NIL") "LIST" "LIST")
) ;Err_CheckArguments
(setq res T)
(foreach s flst
  (setq setting (car s))
  (setq val (cdr s))
  (if (= (substr val 1 1) "$") ;variable
    (if (= (Utl_Member val rtdata) NIL) ;not runtime variable
      (progn
        (setq cval (Utl_CdrAssoc val cdata))
        (if (/= cval NIL)
          (setq flst (subst (cons setting cval) (assoc setting flst) flst))
          (setq res NIL)
        ) ;if
      ) ;progn
    ) ;if
  ) ;if
) ;foreach
(Err_FunctionList NIL)
(setq flst flst)
) ;defun
;-----
; Function:    p_PODS-AddValue
; Purpose:     Builds the table entry for an individual record
; Syntax:      (p_PODS-AddValue flst)
; Inputs:      Flst (List)
; Returns:     The populated values for each record
; References:  acLib
; Notes:       1. If the string value is prefixed with $ it is treated as a variable
;-----
(defun p_PODS-AddValue (flst / f val dlst)
  (Err_FunctionList "p_PODS-AddValue")
  (Err_CheckArguments (list flst) (list "LIST"))
  (foreach f flst
    (setq val (cdr f))
    (if (= val "")
      (setq dlst (cons val dlst))
      (if (= (eval (read val)) NIL)
        (setq dlst (cons val dlst))
        (setq dlst (cons (eval (read val)) dlst))
      ) ;if
    ) ;if
  ) ;foreach
  (Err_FunctionList NIL)
  (setq dlst dlst)
) ;defun
;-----
; Function:    p_PODS-WallThickness
; Purpose:     The wall thickness at the specified chainage
; Syntax:      (p_PODS-WallThickness 2d1 cdata)
; Inputs:      2d1 (Integer/Real), cdata (List)
; Returns:     Wall thickness (String)
; References:  acLib
; Notes:
;-----
(defun p_PODS-WallThickness (2d1 cdata / wtlst k wt wtvalue)
  (Err_FunctionList "p_PODS-WallThickness")
  (Err_CheckArguments (list 2d1 cdata) (list "NUM" "LIST"))
  (setq wtlst (cdr (assoc "WT" cdata)))
  (setq k 0)
  (while (< k (length wtlst))
    (setq wt (nth k wtlst))
    (if (and (>= 2d1 (Cal_Round (nth 0 wt) 1)) (< 2d1 (Cal_Round (nth 1 wt) 1)))
      (progn
        (setq wtvalue (nth 2 wt))
        (setq k (length wtlst))
      ) ;progn
    ) ;if
    (setq k (1+ k))
  ) ;while
  (Err_FunctionList NIL)
  (setq wtvalue wtvalue)
) ;defun

```



```

; -----
; Function:   p_PODS-TCount
; Purpose:   Function to store the number of PODS tables created
; Syntax:    (p_PODS-TCount K Cdata)
; Inputs:    K (Integer), Cdata (List)
; Returns:   The modified cdata (List)
; References: acLib
; Notes:
; -----
(defun p_PODS-TCount (k cdata / ck)
  (Err_FunctionList "p_PODS-TCount")
  (Err_CheckArguments (list k cdata) (list "INT" "LIST"))
  (setq ck (cdr (assoc "TableCount" cdata)))
  (setq cdata (subst (cons "TableCount" (+ ck k)) (assoc "TableCount" cdata) cdata))
  (Err_FunctionList NIL)
  (setq cdata cdata)
) ;defun
; -----
; Function:   p_PODS-RCount
; Purpose:   Function to store the number of PODS attributes created
; Syntax:    (p_PODS-RCount K Cdata)
; Inputs:    K (Integer), Cdata (List)
; Returns:   The modified cdata (List)
; References: acLib
; Notes:
; -----
(defun p_PODS-RCount (k cdata / ck)
  (Err_FunctionList "p_PODS-RCount")
  (Err_CheckArguments (list k cdata) (list "INT" "LIST"))
  (setq ck (cdr (assoc "RecordCount" cdata)))
  (setq cdata
    (subst (cons "RecordCount" (+ ck k)) (assoc "RecordCount" cdata) cdata)
  ) ;setq
  (Err_FunctionList NIL)
  (setq cdata cdata)
) ;defun
; -----
; Function:   p_PODS-TableHeader
; Purpose:   Builds the table header for the PODS table
; Syntax:    (p_PODS-TableHeader Flst)
; Inputs:    Flst (List)
; Returns:   The modified variable list with the variable values added
; References: acLib
; Notes:
; -----
(defun p_PODS-TableHeader (flst / f hlst)
  (Err_FunctionList "p_PODS-TableHeader")
  (Err_CheckArguments (list flst) (list "LIST"))
  (foreach f flst
    (setq hlst (cons (car f) hlst))
  ) ;foreach
  (setq hlst (list (Lst_List->String (reverse hlst) "\t")))
  (Err_FunctionList NIL)
  (setq hlst hlst)
) ;defun
; -----
; Function:   p_PODS-ExportLineLoop
; Purpose:   Builds the PODS LineLoop table
; Syntax:    (p_PODS-ExportLineLoop cdata)
; Inputs:    Cdata (List)
; Returns:   The modified cdata (List)
; References: acLib
; Notes:
; -----
(defun p_PODS-ExportLineLoop (cdata / table fname flst rtdata tlst dlst)
  (Err_FunctionList "p_PODS-ExportLineLoop")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "LineLoop")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  ; Add data to the cdata variable
  (setq cdata (cons (cons "$LineLoopGUID" (Utl_GUID)) cdata))
  ; List of runtime variables
  (setq rtdata NIL)

```

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```

(if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
  ; All required variables present
  (progn
    (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
    (setq tlst (p_PODS-TableHeader flst)) ;build header
    (setq dlst (p_PODS-AddValue flst))
    (setq tlst (reverse (cons (Lst_List->String (reverse dlst) "\t") tlst)))
    (Fil_Write fname "w" (cons NIL tlst))
    (setq cdata (p_PODS-RCount 1 cdata))
    (setq cdata (p_PODS-TCount 1 cdata))
  ) ;progn
  (alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:    p_PODS-ExportStationSeries
; Purpose:    Builds the PODS StationSeries table
; Syntax:     (p_PODS-ExportStationSeries cdata)
; Inputs:     Cdata (List)
; Returns:    The modified cdata (List)
; References: acLib
; Notes:
; -----
(defun p_PODS-ExportStationSeries (cdata / table fname flst rtdata tlst k $GUID
                                   $RefMode dlst)
  (Err_FunctionList "p_PODS-ExportStationSeries")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "StationSeries")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  ; Add data to the cdata variable
  (setq cdata (cons (cons "$CStationSeriesGUID" (Utl_GUID)) cdata))
  (setq cdata (cons (cons "$EStationSeriesGUID" (Utl_GUID)) cdata))
  ; List of runtime variables
  (setq rtdata (list "$GUID" "$RefMode"))
  (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
    ; All required variables present
    (progn
      (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
      (setq tlst (p_PODS-TableHeader flst)) ;build header
      (setq k 0)
      (while (< k 2)
        (if (= k 0)
          (progn
            (setq $GUID (cdr (assoc "$CStationSeriesGUID" cdata)))
            (setq $RefMode "Continuous")
          ) ;prong
          (progn
            (setq $GUID (cdr (assoc "$EStationSeriesGUID" cdata)))
            (setq $RefMode "Engineering")
          ) ;progn
        ) ;if
        (setq dlst (p_PODS-AddValue flst))
        (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
        (setq k (1+ k))
      ) ;while
      (Fil_Write fname "w" (cons NIL (reverse tlst)))
      (setq cdata (p_PODS-RCount 2 cdata))
      (setq cdata (p_PODS-TCount 1 cdata))
    ) ;progn
    (alert (strcat "Error: Variables missing p_PODS-Export" table))
  ) ;if
  (Err_FunctionList NIL)
  (setq cdata cdata)
) ;defun

```

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```

; -----
; Function:   p_PODS-ExportControlPoint
; Purpose:   Builds the PODS ControlPoint table
; Syntax:    (p_PODS-ExportControlPoint elst cdata)
; Inputs:    Elst (Entity list), cdata (List)
; Returns:   The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportControlPoint (elst cdata / table fname flst rtdata tlst ptlst
                                iplst k pt $Angle $Vtype $AngDesc bd
                                $2D1 $X $Y $Z $GUID dlst)

  (Err_FunctionList "p_PODS-ExportControlPoint")
  (Err_CheckArguments (list elst cdata) (list "ELIST" "LIST"))
  (setq table "ControlPoint")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  ; List of runtime variables
  (setq rtdata (list "$GUID" "$2D1" "$X" "$Y" "$Z" "$Angle" "$Vtype" "$AngDesc"))
  (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
    ; All required variables present
    (progn
      (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
      (setq tlst (p_PODS-TableHeader flst)) ;build header
      (setq ptlst (Ply_Vertices elst))
      (setq iplst (Ply_IPList elst))
      (setq k 0)
      (dos_progbar (strcat "Exporting PODS " table " Table") (length ptlst))
      (while (< k (length ptlst))
        (dos_progbar k)
        (setq pt (nth k ptlst))
        (if (= (member k iplst) NIL)
          (setq $Angle "" $Vtype "" $AngDesc "")
          (progn
            (setq bd (Ply_BendAtPoint elst pt))
            (setq $Angle (rtos (Con_Rad->Deg (nth 0 bd) 2 0))
            (setq $Vtype "IP")
            (setq $AngDesc (nth 3 bd))
            ) ;progn
          ) ;if
        (setq $2D1 (Ply_Point->Chainage2D (car elst) pt))
        (if (= $2D1 NIL) (setq $2D1 "-1") (setq $2D1 (rtos $2D1 2 3)))
        (setq $X
          (rtos (nth 0 pt) 2 3) $Y (rtos (nth 1 pt) 2 3) $Z (rtos (nth 2 pt) 2 3)
        ) ;setq
        (setq $GUID (Utl_GUID))
        (setq dlst (p_PODS-AddValue flst))
        (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
        (setq k (1+ k))
      ) ;while
      (Fil_Write fname "w" (cons NIL (reverse tlst)))
      (setq cdata (p_PODS-RCount (length ptlst) cdata))
      (setq cdata (p_PODS-TCount 1 cdata))
      (dos_progbar)
    ) ;progn
  ) ;if
  (Err_FunctionList NIL)
  (setq cdata cdata)
) ;defun
; -----
; Function:   p_PODS-ExportRoutingNote
; Purpose:   Builds the PODS RoutingNote table
; Syntax:    (p_PODS-ExportRoutingNote cdata)
; Inputs:    cdata (List)
; Returns:   The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportRoutingNote (cdata / table fname flst app sset rtdata tlst k
                                ename $Handle $GUID $X $Y $Z $2D1 ang
                                angdesc $AngleAngDesc $IPTag $IPNo dlst)

  (Err_FunctionList "p_PODS-ExportRoutingNote")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "RoutingNote")

```

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```

(setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
(setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
(setq app "IPD_X-IPS")
(setq sset (Xda_Selection app "#2D1"))
(if (= sset NIL)
  (alert "Error: No IP Extended Entity Data found.")
  (progn
    ; List of runtime variables
    (setq rtdata
      (list
        "$Handle" "$GUID" "$IPTag" "$IPNo" "$2D1" "$X" "$Y" "$Z" "$AngleAngDesc"
      ) ;list
    ) ;setq
  (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
    ; All req'd variables present
    (progn
      (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
      (setq tlst (p_PODS-TableHeader flst)) ;build header
      (setq k 0)
      (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
      (while (< k (sslength sset))
        (dos_progbar k)
        (setq ename (ssname sset k))
        (setq $Handle (cdr (assoc 5 (entget ename))))
        (setq $GUID (Utl_GUID))
        (setq $X (Xda_GetValue ename app "#X1"))
        (setq $Y (Xda_GetValue ename app "#Y1"))
        (setq $Z "0")
        (setq $2D1 (Xda_GetValue ename app "#2D1"))
        (setq ang (Xda_GetValue ename app "#HANG"))
        (setq angdesc (Xda_GetValue ename app "#HDESC"))
        (setq $AngleAngDesc ang)
        (setq $IPTag (Xda_GetValue ename app "#TAG"))
        (setq $IPNo (itoa (+ k 1)))
        (setq dlst (p_PODS-AddValue flst))
        (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
        (setq k (+ k))
      ) ;while
      (Fil_Write fname "w" (cons NIL (reverse tlst)))
      (setq cdata (p_PODS-RCount (sslength sset) cdata))
      (setq cdata (p_PODS-TCount 1 cdata))
      (dos_progbar)
    ) ;progn
    (alert (strcat "Error: Variables missing p_PODS-Export" table))
  ) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
;-----
; Function:    p_PODS-ExportRoad
; Purpose:    Builds the PODS Road table
; Syntax:    (p_PODS-ExportRoad cdata)
; Inputs:    cdata (List)
; Returns:   The modified cdata (List)
; References: acLib, dosLib
; Notes:
;-----
(defun p_PODS-ExportRoad (cdata / table fname flst app sset rtdata tlst k ename $Code
                          $Handle $GUID $X $Y $Z $2D1 $Angle $StdDetail
                          $Width $Source $XNO $PDesc dlst)
  (Err_FunctionList "p_PODS-ExportRoad")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "Road")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-XPTS")
  ; List of runtime variables
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn
      (setq rtdata

```

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```

(list
  "$Handle" "$GUID" "$Source" "$PDesc" "$XNO" "$2D1" "$X" "$Y" "$Z" "$Angle"
  "$StdDetail" "$Code" "$Width"
) ;list
) ;setq
) ;if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
; All req'd variables present
(progn
  (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
  (setq tlst (p_PODS-TableHeader flst)) ;build header
  (setq k 0)
  (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
  (while (< k (sslength sset))
    (dos_progbar k)
    (setq ename (ssname sset k))
    (setq $Code (Xda_GetValue ename app "#CODE"))
    (if (or (= $Code "RDX") (= $Code "SRX") (= $Code "TRX"))
      (progn
        (setq $Handle (cdr (assoc 5 (entget ename))))
        (setq $GUID (Utl_GUID))
        (setq $X (Xda_GetValue ename app "#X1"))
        (setq $Y (Xda_GetValue ename app "#Y1"))
        (setq $Z "0")
        (setq $2D1 (Xda_GetValue ename app "#2D1"))
        (setq $Angle (Xda_GetValue ename app "#ANGLE"))
        (setq $StdDetail (Xda_GetValue ename app "#STDDETAIL"))
        (setq $Width (Xda_GetValue ename app "#WIDTH"))
        (setq $Source (Xda_GetValue ename app "#SOURCE"))
        (setq $XNO (Xda_GetValue ename app "#XNO"))
        (setq $PDesc (Xda_GetValue ename app "#PDESC"))
        (setq dlst (p_PODS-AddValue flst))
        (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
        (setq cdata (p_PODS-RCount 1 cdata))
      ) ;progn
    ) ;if
    (setq k (1+ k))
  ) ;while
  (Fil_Write fname "w" (cons NIL (reverse tlst)))
  (setq cdata (p_PODS-TCount 1 cdata))
  (dos_progbar)
) ;progn
(alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
;
; -----
; Function: p_PODS-ExportRailroad
; Purpose: Builds the PODS Railroad table
; Syntax: (p_PODS-ExportRailroad cdata)
; Inputs: cdata (List)
; Returns: The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportRailroad (cdata / table fname flst app sset rtdata tlst k ename
                             $Code $Handle $GUID $X $Y $Z $2D1 $Angle
                             $StdDetail $Width $Source $XNO $PDesc dlst)
  (Err_FunctionList "p_PODS-ExportRailroad")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "Railroad")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-XPTS")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata
        (list
          "$Handle" "$GUID" "$Source" "$PDesc" "$XNO" "$2D1" "$X" "$Y" "$Z" "$Angle"

```

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```

    "$StdDetail" "$Code" "$Width"
  ) ;list
) ;setq
(if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
  ; All req'd variables present
  (progn
    (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
    (setq tlst (p_PODS-TableHeader flst)) ;build header
    (setq k 0)
    (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
    (while (< k (sslength sset))
      (dos_progbar k)
      (setq ename (ssname sset k))
      (setq $Code (Xda_GetValue ename app "#CODE"))
      (if (= $Code "RLX")
        (progn
          (setq $Handle (cdr (assoc 5 (entget ename))))
          (setq $GUID (Utl_GUID))
          (setq $X (Xda_GetValue ename app "#X1"))
          (setq $Y (Xda_GetValue ename app "#Y1"))
          (setq $Z "0")
          (setq $2D1 (Xda_GetValue ename app "#2D1"))
          (setq $Angle (Xda_GetValue ename app "#ANGLE"))
          (setq $StdDetail (Xda_GetValue ename app "#STDDETAIL"))
          (setq $Width (Xda_GetValue ename app "#WIDTH"))
          (setq $Source (Xda_GetValue ename app "#SOURCE"))
          (setq $XNO (Xda_GetValue ename app "#XNO"))
          (setq $PDesc (Xda_GetValue ename app "#PDESC"))
          (setq dlst (p_PODS-AddValue flst))
          (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
          (setq cdata (p_PODS-RCount 1 cdata))
        ) ;progn
      ) ;if
      (setq k (1+ k))
    ) ;while
    (Fil_Write fname "w" (cons NIL (reverse tlst)))
    (setq cdata (p_PODS-TCount 1 cdata))
    (dos_progbar)
  ) ;progn
  (alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:    p_PODS-ExportWaterway
; Purpose:    Builds the PODS Waterway table
; Syntax:    (p_PODS-ExportWaterway cdata)
; Inputs:    cdata (List)
; Returns:    The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportWaterway (cdata / table fname flst app sset rtdata tlst k ename
                             $Code $Handle $GUID $X $Y $Z $2D1 $Angle
                             $StdDetail $Width $Source $XNO $PDesc dlst)
  (Err_FunctionList "p_PODS-ExportWaterway")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "Waterway")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-XPTS")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata
        (list
          "$Handle" "$GUID" "$Source" "$PDesc" "$XNO" "$2D1" "$X" "$Y" "$Z" "$Angle"
          "$StdDetail" "$Code" "$Width"
        ) ;list
      ) ;list
    ) ;progn
  ) ;if
) ;defun

```

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```

) ;setq
(if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
  ; All req'd variables present
  (progn
    (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
    (setq tlst (p_PODS-TableHeader flst)) ;build header
    (setq k 0)
    (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
    (while (< k (sslength sset))
      (dos_progbar k)
      (setq ename (ssname sset k))
      (setq $Code (Xda_GetValue ename app "#CODE"))
      (if
        (or
          (= $Code "RVX") (= $Code "CLX") (= $Code "GLX")
          (= $Code "STX") (= $Code "DTX")
        ) ;or
        (progn
          (setq $Handle (cdr (assoc 5 (entget ename))))
          (setq $GUID (Utl_GUID))
          (setq $X (Xda_GetValue ename app "#X1"))
          (setq $Y (Xda_GetValue ename app "#Y1"))
          (setq $Z "0")
          (setq $2D1 (Xda_GetValue ename app "#2D1"))
          (setq $Angle (Xda_GetValue ename app "#ANGLE"))
          (setq $StdDetail (Xda_GetValue ename app "#STDDETAIL"))
          (setq $Width (Xda_GetValue ename app "#WIDTH"))
          (if (= (type $Width) 'STR) (setq $Width ""))
          (setq $Source (Xda_GetValue ename app "#SOURCE"))
          (setq $XNO (Xda_GetValue ename app "#XNO"))
          (setq $PDesc (Xda_GetValue ename app "#PDESC"))
          (setq dlst (p_PODS-AddValue flst))
          (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
          (setq cdata (p_PODS-RCount 1 cdata))
        ) ;progn
      ) ;if
      (setq k (1+ k))
    ) ;while
    (Fil_Write fname "w" (cons NIL (reverse tlst)))
    (setq cdata (p_PODS-TCount 1 cdata))
    (dos_progbar)
  ) ;progn
  (alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function: p_PODS-ExportForeignLineCrossing
; Purpose: Builds the PODS Road table
; Syntax: (p_PODS-ExportForeignLineCrossing cdata)
; Inputs: cdata (List)
; Returns: The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportForeignLineCrossing (cdata / table fname flst app sset rtdata
                                         tlst k ename $Code $Handle $GUID $X
                                         $Y $Z $2D1 $Angle $StdDetail $Width
                                         $Height $Source $XNO $PDesc
                                         $LineClearance $LineBelowGroundLF
                                         Cover height width dlst)
  (Err_FunctionList "p_PODS-ExportForeignLineCrossing")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "ForeignLineCrossing")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-XPTS")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn

```

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```

; List of runtime variables
(setq rtdata
  (list
    "$Handle" "$GUID" "$Source" "$PDesc" "$XNO" "$2D1" "$X" "$Y" "$Z" "$Angle"
    "$StdDetail" "$Code" "$Width" "$LineBelowGroundLF" "$LineClearance"
    "$Height"
  ) ;list
) ;setq
(if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
  ; All req'd variables present
  (progn
    (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
    (setq tlst (p_PODS-TableHeader flst)) ;build header
    (setq k 0)
    (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
    (while (< k (sslength sset))
      (dos_progbar k)
      (setq ename (ssname sset k))
      (setq $Code (Xda_GetValue ename app "#CODE"))
      (if (or (= $Code "FXO") (= $Code "FXA") (= $Code "FXU"))
        (progn
          ; Set record variables
          (setq $Handle (cdr (assoc 5 (entget ename))))
          (setq $GUID (Utl_GUID))
          (setq $X (Xda_GetValue ename app "#X1"))
          (setq $Y (Xda_GetValue ename app "#Y1"))
          (setq $Z "0")
          (setq $2D1 (Xda_GetValue ename app "#2D1"))
          (setq $Angle (Xda_GetValue ename app "#ANGLE"))
          (setq $StdDetail (Xda_GetValue ename app "#STDDETAIL"))
          (setq $Width (Xda_GetValue ename app "#WIDTH"))
          (if (= (type $Width) 'STR) (setq $Width ""))
          (setq $Height (Xda_GetValue ename app "#HEIGHT"))
          (if (= (type $Height) 'STR) (setq $Height ""))
          (setq $Source (Xda_GetValue ename app "#SOURCE"))
          (setq $XNO (Xda_GetValue ename app "#XNO"))
          (setq $PDesc (Xda_GetValue ename app "#PDESC"))
          (cond
            (
              (= $Code "FXO")
              (setq $LineClearance "")
              (setq $LineBelowGroundLF "N")
            ) ;case
            (
              (= $Code "FXA")
              (setq $Height "")
              (setq $LineClearance "")
              (setq $LineBelowGroundLF "N")
            ) ;case
            (
              (= $Code "FXU")
              (setq $Height "")
              (setq cover
                (Con_String->Number (Xda_GetValue ename app "COVER")))
              ) ;setq
              (setq height (Con_String->Number $Height))
              (setq width (Con_String->Number $Width))
              (if
                (and (/= $Width NIL) (/= cover NIL) (/= height NIL))
                (setq $LineClearance (- cover (+ width height)))
                (setq $LineClearance "")
              ) ;if
              (setq $LineBelowGroundLF "Y")
            ) ;case
          ) ;cond
          (setq dlst (p_PODS-AddValue flst))
          (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
          (setq cdata (p_PODS-RCount 1 cdata))
        ) ;progn
      ) ;if
      (setq k (1+ k))
    ) ;while
  ) ;write filename
  (setq cdata (p_PODS-TCount 1 cdata))

```



```

        (dos_progbar)
    ) ;progn
    (alert (strcat "Error: Variables missing p_PODS-Export" table))
  ) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:    p_PODS-ExportHCACASegment
; Purpose:    Builds the PODS HCACASegment table
; Syntax:    (p_PODS-ExportHCACASegment cdata)
; Inputs:    cdata (List)
; Returns:   The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportHCACASegment (cdata / table fname flst app sset rtdata tlst k
                                ename $Handle $GUID $2D1 $2D2 $Properties
                                $Class dlst)
  (Err_FunctionList "p_PODS-ExportHCACASegment")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "HCACASegment")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-CLASSLOCATION")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Class Location Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata (list "$Handle" "$GUID" "$2D1" "$2D2" "$PROPERTIES" "$CLASS"))
      (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
        ; All req'd variables present
        (progn
          (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
          (setq tlst (p_PODS-TableHeader flst)) ;build header
          (setq k 0)
          (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
          (while (< k (sslength sset))
            (dos_progbar k)
            (setq ename (ssname sset k))
            (setq $Handle (cdr (assoc 5 (entget ename))))
            (setq $GUID (Utl_GUID))
            (setq $2D1 (Xda_GetValue ename app "#2D1"))
            (setq $2D2 (Xda_GetValue ename app "#2D2"))
            (setq $Properties
              (strcat "Total Properties: " (Xda_GetValue ename app "#Properties")))
            ) ;setq
            (setq $Class (Xda_GetValue ename app "#Class"))
            (setq dlst (p_PODS-AddValue flst))
            (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
            (setq k (1+ k))
          ) ;while
          (Fil_Write fname "w" (cons NIL (reverse tlst)))
          (setq cdata (p_PODS-RCount (sslength sset) cdata))
          (setq cdata (p_PODS-TCount 1 cdata))
          (dos_progbar)
        ) ;progn
      (alert (strcat "Error: Variables missing p_PODS-Export" table))
    ) ;if
  ) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun

```

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```

; -----
; Function:    p_PODS-ExportHCABoundary
; Purpose:    Builds the PODS HCACASegment table
; Syntax:     (p_PODS-ExportHCABoundary cdata)
; Inputs:     cdata (List)
; Returns:    The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportHCABoundary (cdata / table fname flst app sset rtdata tlst k
                               ename $Handle $GUID $2D1 $2D2 $Value dlst)
  (Err_FunctionList "p_PODS-ExportHCABoundary")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "HCABoundary")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-REFDWG")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
      (alert "Error: No Class Location Extended Entity Data found.")
      (progn
        ; List of runtime variables
        (setq rtdata (list "$Handle" "$GUID" "$2D1" "$2D2" "$VALUE"))
        (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
            ; All req'd variables present
            (progn
              (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
              (setq tlst (p_PODS-TableHeader flst)) ;build header
              (setq k 0)
              (dos_progbar (strcat "Exporting PODS " table " Table") (sslenght sset))
              (while (< k (sslenght sset))
                (dos_progbar k)
                (setq ename (ssname sset k))
                (setq $Handle (cdr (assoc 5 (entget ename))))
                (setq $GUID (Utl_GUID))
                (setq $2D1 (Xda_GetValue ename app "#2D1"))
                (setq $2D2 (Xda_GetValue ename app "#2D2"))
                (setq $Value (Xda_GetValue ename app "VALUE"))
                (setq dlst (p_PODS-AddValue flst))
                (setq tlst (cons (Lst_List->String (reverse dlst) "\\t") tlst))
                (setq k (1+ k))
              ) ;while
              (Fil_Write fname "w" (cons NIL (reverse tlst)))
              (setq cdata (p_PODS-RCount (sslenght sset) cdata))
              (setq cdata (p_PODS-TCount 1 cdata))
              (dos_progbar)
            ) ;progn
            (alert (strcat "Error: Variables missing p_PODS-Export" table))
          ) ;if
        ) ;progn
      ) ;if
  (Err_FunctionList NIL)
  (setq cdata cdata)
) ;defun
; -----
; Function:    p_PODS-ExportPipeSegment
; Purpose:    Builds the PODS PipeSegment table
; Syntax:     (p_PODS-ExportPipeSegment cdata)
; Inputs:     cdata (List)
; Returns:    The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportPipeSegment (cdata / table fname flst app rtdata sset flst tlst k
                                ename $Handle $GUID $2D1 $2D2 $Value
                                $DesignFactor $ID wtlst dlst)
  (Err_FunctionList "p_PODS-ExportPipeSegment")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "PipeSegment")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-WT")
  ; List of runtime variables
  (setq rtdata (list "$Handle" "$GUID" "$2D1" "$2D2" "$VALUE" "$DesignFactor" "$ID"))

```

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```

(setq sset (Xda_Selection app "#2D1"))
(if (= sset NIL)
  (alert "Error: No Wall Thickness Extended Entity Data found.")
  (progn
    (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
      ; All req'd variables present
      (progn
        (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
        (setq tlst (p_PODS-TableHeader flst)) ;build header
        (setq k 0)
        (dos_progbar (strcat "Exporting PODS " table " Table") (sslenght sset))
        (while (< k (sslenght sset))
          (dos_progbar k)
          (setq ename (ssname sset k))
          (setq $Handle (cdr (assoc 5 (entget ename))))
          (setq $GUID (Utl_GUID))
          (setq $2D1 (Xda_GetValue ename app "#2D1"))
          (setq $2D2 (Xda_GetValue ename app "#2D2"))
          (setq $Value (Xda_GetValue ename app "VALUE"))
          (cond
            ((= $Value "16.7") (setq $DesignFactor "0.72" $ID "1185.6"))
            ((= $Value "20.1") (setq $DesignFactor "0.6" $ID "1178.8"))
            ((= $Value "24.1") (setq $DesignFactor "0.5" $ID "1170.8"))
          ) ;cond
          (setq wtlst (cons (list (atof $2D1) (atof $2D2) $Value) wtlst))
          (setq dlst (p_PODS-AddValue flst))
          (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
          (setq k (1+ k))
        ) ;while
        (Fil_Write fname "w" (cons NIL (reverse tlst)))
        ;add wall thickness sections
        (setq cdata (cons (cons "WT" (reverse wtlst)) cdata))
        (setq cdata (p_PODS-RCount (sslenght sset) cdata))
        (setq cdata (p_PODS-TCount 1 cdata))
        (dos_progbar)
      ) ;progn
    (alert (strcat "Error: Variables missing p_PODS-Export" table))
  ) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:    p_PODS-ExportElbow
; Purpose:    Builds the PODS Elbow table
; Syntax:    (p_PODS-ExportElbow cdata)
; Inputs:    cdata (List)
; Returns:    The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportElbow (cdata / table fname flst app sset rtdata tlst k ename
                          ibend $Handle $X $Y $Z $2D1 $IPTag bs ang k1
                          $IBend $GUID dlst)
  (Err_FunctionList "p_PODS-ExportElbow")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "Elbow")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-IPS")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No IP Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata
        (list "$Handle" "$GUID" "$IPTag" "$2D1" "$X" "$Y" "$Z" "$IBend" "$WT"))
      ) ;setq
    (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
      ; All req'd variables present
      (progn
        (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
        (setq tlst (p_PODS-TableHeader flst)) ;build header

```

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```

(setq k 0)
(dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
(while (< k (sslength sset))
  (dos_progbar k)
  (setq ename (ssname sset k))
  (setq ibend (Xda_GetValue ename app "IBEND"))
  (if (/= ibend "")
    (progn
      (setq $Handle (cdr (assoc 5 (entget ename))))
      (setq $X (Xda_GetValue ename app "#X1"))
      (setq $Y (Xda_GetValue ename app "#Y1"))
      (setq $Z "0")
      (setq $2D1 (Xda_GetValue ename app "#2D1"))
      (setq $WT (p_pods-wallthickness (atof $2D1) cdata))
      (setq $IPTag (Xda_GetValue ename app "#TAG"))
      (foreach bs (Lst_String->List ibend " ")
        (setq ang (nth 0 (Lst_String->List bs "/")))
        (setq k1 0)
        (while (< k1 (atoi (nth 1 (Lst_String->List bs "/"))))
          (setq $IBend ang)
          (setq $GUID (Utl_GUID))
          (setq dlst (p_PODS-AddValue flst))
          (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
          (setq k1 (1+ k1))
        ) ;while
      ) ;foreach
    ) ;progn
  ) ;if
  (setq k (1+ k))
) ;while
(Fil_Write fname "w" (cons NIL (reverse tlst)))
(setq cdata (p_PODS-RCount (sslength sset) cdata))
(setq cdata (p_PODS-TCount 1 cdata))
(dos_progbar)
) ;progn
(alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:   p_PODS-ExportConcreteSlab
; Purpose:   Builds the PODS ConcreteSlab table
; Syntax:    (p_PODS-ExportConcreteSlab cdata)
; Inputs:    cdata (List)
; Returns:   The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportConcreteSlab (cdata / table fname flst app sset rtdata tlst k
                                ename slabs $Handle $GUID $X $Y $Z $XNO 2d1
                                $2D1 $2D2 dlst)
  (Err_FunctionList "p_PODS-ExportConcreteSlab")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "ConcreteSlab")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-XPTS")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata (list "$Handle" "$GUID" "$XNO" "$2D1" "$2D2" "$X" "$Y" "$Z"))
      (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
        ; All req'd variables present
        (progn
          (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
          (setq tlst (p_PODS-TableHeader flst)) ;build header
          (setq k 0)
          (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
          (while (< k (sslength sset))

```

```

(dos_progbar k)
(setq ename (ssname sset k))
(setq slabs (Xda_GetValue ename app "SLABS"))
(if (/= slabs "")
  (progn
    (setq slabs (Con_String->Number slabs))
    (if (/= slabs NIL)
      (progn
        (setq $Handle (cdr (assoc 5 (entget ename))))
        (setq $GUID (Utl_GUID))
        (setq $X (Xda_GetValue ename app "#X1"))
        (setq $Y (Xda_GetValue ename app "#Y1"))
        (setq $Z "0")
        (setq $XNO (Xda_GetValue ename app "#XNO"))
        (setq 2d1 (atof (Xda_GetValue ename app "#2D1")))
        (setq $2D1 (- 2d1 (/ slabs 2)))
        (setq $2D2 (+ 2d1 (/ slabs 2)))
        (setq dlst (p_PODS-AddValue flst))
        (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
        (setq cdata (p_PODS-RCount 1 cdata))
      ) ;progn
    ) ;if
  ) ;progn
) ;if
(setq k (1+ k))
) ;while
(Fil_Write fname "w" (cons NIL (reverse tlst)))
(setq cdata (p_PODS-TCount 1 cdata))
(dos_progbar)
) ;progn
(alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:    p_PODS-ExportCoating
; Purpose:    Builds the PODS Coating table
; Syntax:    (p_PODS-ExportCoating cdata)
; Inputs:    cdata (List)
; Returns:    The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportCoating (cdata / table fname flst app sset rtdata tlst k ename
                             conc $Handle $GUID $X $Y $Z $XNO 2d1 $2D1 $2D2
                             dlst)
  (Err_FunctionList "p_PODS-ExportCoating")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "Coating")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS " table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-XPTS")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata (list "$Handle" "$GUID" "$XNO" "$2D1" "$2D2" "$X" "$Y" "$Z"))
      (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
        ; All req'd variables present
        (progn
          (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
          (setq tlst (p_PODS-TableHeader flst)) ;build header
          (setq k 0)
          (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
          (while (< k (sslength sset))
            (dos_progbar k)
            (setq ename (ssname sset k))
            (setq conc (Xda_GetValue ename app "CONCRETE"))
            (if (/= conc "")
              (progn

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(setq conc (Con_String->Number conc))
(if (/= conc NIL)
  (progn
    (setq $Handle (cdr (assoc 5 (entget ename))))
    (setq $GUID (Utl_GUID))
    (setq $X (Xda_GetValue ename app "#X1"))
    (setq $Y (Xda_GetValue ename app "#Y1"))
    (setq $Z "0")
    (setq $XNO (Xda_GetValue ename app "#XNO"))
    (setq 2d1 (atof (Xda_GetValue ename app "#2D1")))
    (setq $2D1 (- 2d1 (/ conc 2)))
    (setq $2D2 (+ 2d1 (/ conc 2)))
    (setq dlst (p_PODS-AddValue flst))
    (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
    (setq cdata (p_PODS-RCount 1 cdata))
  ) ;progn
) ;if
) ;progn
) ;if
(setq k (1+ k))
) ;while
(Fil_Write fname "w" (cons NIL (reverse tlst)))
(setq cdata (p_PODS-TCount 1 cdata))
(dos_progbar)
) ;progn
(alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:   p_PODS-ExportJunctionBox
; Purpose:   Builds the PODS JunctionBox table
; Syntax:    (p_PODS-ExportJunctionBox cdata)
; Inputs:    cdata (List)
; Returns:   The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportJunctionBox (cdata / table fname flst app sset rtdata tlst k
                               ename conc $Handle $GUID $X $Y $Z $CPTag
                               $2D1 dlst)

  (Err_FunctionList "p_PODS-ExportJunctionBox")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "JunctionBox")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-CP")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata (list "$Handle" "$GUID" "$CPTag" "$2D1" "$X" "$Y" "$Z"))
      (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
        ; All req'd variables present
        (progn
          (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
          (setq tlst (p_PODS-TableHeader flst)) ;build header
          (setq k 0)
          (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
          (while (< k (sslength sset))
            (dos_progbar k)
            (setq ename (ssname sset k))
            (setq $Handle (cdr (assoc 5 (entget ename))))
            (setq $GUID (Utl_GUID))
            (setq $X (Xda_GetValue ename app "#X1"))
            (setq $Y (Xda_GetValue ename app "#Y1"))
            (setq $Z "0")
            (setq $CPTag (Xda_GetValue ename app "CPTAG"))
            (setq $2D1 (Xda_GetValue ename app "#2D1"))
            (setq dlst (p_PODS-AddValue flst))
          )
        )
      )
    )
  )
)

```

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```

        (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
        (setq cdata (p_PODS-RCount 1 cdata))
        (setq k (1+ k))
    ) ;while
    (Fil_Write fname "w" (cons NIL (reverse tlst)))
    (setq cdata (p_PODS-TCount 1 cdata))
    (dos_progbar)
) ;progn
(alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:    p_PODS-ExportMarker
; Purpose:    Builds the PODS JunctionBox table
; Syntax:    (p_PODS-ExportMarker cdata)
; Inputs:    cdata (List)
; Returns:    The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportMarker (cdata / table fname flst app sset rtdata tlst k ename
                          $Handle $X $Y $Z $Tag $2D1 $2DKP $Type $Desc dlst
                          nmk pmk)
  (Err_FunctionList "p_PODS-ExportMarker")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "Marker")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-AM")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn
      ; List of runtime variables
      (setq rtdata
        (list "$Handle" "$GUID" "$Tag" "$2D1" "$X" "$Y" "$Z" "$2DKP" "$Type" "$DESC"))
      ) ;setq
      (if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
        ; All req'd variables present
        (progn
          (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
          (setq tlst (p_PODS-TableHeader flst)) ;build header
          (setq k 0)
          (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
          (while (< k (sslength sset))
            (dos_progbar k)
            (setq ename (ssname sset k))
            (if (= (strcase (Xda_GetValue ename app "SHOW")) "YES")
              (progn
                (setq $Handle (cdr (assoc 5 (entget ename))))
                (setq $GUID (Utl_GUID))
                (setq $X (Xda_GetValue ename app "#X1"))
                (setq $Y (Xda_GetValue ename app "#Y1"))
                (setq $Z "0")
                (setq $Tag (Xda_GetValue ename app "#TAG"))
                (setq $2D1 (Xda_GetValue ename app "#2D1"))
                (setq $2DKP (rtos (/ (atof $2D1) 1000.0) 2 3))
                (setq $Type "Aerial")
                (setq $Desc "")
                (setq dlst (p_PODS-AddValue flst))
                (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
                (setq cdata (p_PODS-RCount 1 cdata))
              ) ;progn
            ) ;if
            (setq k (1+ k))
          ) ;while
          (setq app "IPD_X-XPTS")
          (setq sset (Xda_Selection app "#2D1"))
          (if (= sset NIL)
            (alert "Error: No Crossing Extended Entity Data found.")
          )
        )
      )
    )
  )

```

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```

(progn
  (setq k 0)
  (dos_progbar (strcat "Exporting PODS " table " Table") (sslength sset))
  (while (< k (sslength sset))
    (dos_progbar k)
    (setq ename (ssname sset k))
    (setq nmk (Xda_GetValue ename app "NMK"))
    (setq pmk (Xda_GetValue ename app "PMK"))
    (if (or (/= nmk "") (/= pmk ""))
      (progn
        (setq $Handle (cdr (assoc 5 (entget ename))))
        (setq $GUID (Utl_GUID))
        (setq $X (Xda_GetValue ename app "#X1"))
        (setq $Y (Xda_GetValue ename app "#Y1"))
        (setq $Z "0")
        (setq $Tag (Xda_GetValue ename app "#XNO"))
        (setq $2D1 (Xda_GetValue ename app "#2D1"))
        (setq $2DKP (rtos (/ (atof $2D1) 1000.0) 2 3))
        (setq $Type "Pipeline")
        (cond
          (
            (and (/= nmk "") (/= pmk ""))
            (setq $Desc "2 markers, one each side of crossing")
          ) ;case
          (
            (and (/= nmk "") (= pmk ""))
            (setq $Desc "1 marker on the negative side of the crossing")
          ) ;case
          (
            (and (= nmk "") (/= pmk ""))
            (setq $Desc "1 marker on the positive side of the crossing")
          ) ;case
        ) ;cond
        (setq dlst (p_PODS-AddValue flst))
        (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
        (setq cdata (p_PODS-RCount 1 cdata))
      ) ;progn
    ) ;if
    (setq k (1+ k))
  ) ;while
) ;progn
) ;if
(Fil_Write fname "w" (cons NIL (reverse tlst)))
(setq cdata (p_PODS-TCount 1 cdata))
(dos_progbar)
) ;progn
(alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
; Function:   p_PODS-ExportValve
; Purpose:    Builds the PODS Valve table
; Syntax:     (p_PODS-ExportValve cdata)
; Inputs:     cdata (List)
; Returns:    The modified cdata (List)
; References: acLib, dosLib
; Notes:
; -----
(defun p_PODS-ExportValve (cdata / table fname flst app sset rtdata tlst k ename
                          $Handle $GUID $X $Y $Z $Value $2D1 dlst)
  (Err_FunctionList "p_PODS-ExportValve")
  (Err_CheckArguments (list cdata) (list "LIST"))
  (setq table "Valve")
  (setq fname (strcat (Utl_CdrAssoc "path" cdata) "PODS_" table ".txt"))
  (setq flst (Ini_Read (list (Utl_CdrAssoc "ifile" cdata) (strcat "[" table "]"))))
  (setq app "IPD_X-VALVES")
  (setq sset (Xda_Selection app "#2D1"))
  (if (= sset NIL)
    (alert "Error: No Crossing Extended Entity Data found.")
    (progn

```



```

; List of runtime variables
(setq rtdata (list "$Handle" "$GUID" "$Value" "$2D1" "$X" "$Y" "$Z"))
(if (= (p_PODS-ExportCheckVariables rtdata cdata flst) T)
  ; All req'd variables present
  (progn
    (setq flst (p_PODS-SetVars rtdata cdata flst)) ;set variables
    (setq tlst (p_PODS-TableHeader flst)) ;build header
    (setq k 0)
    (dos_progn (strcat "Exporting PODS " table " Table") (sslength sset))
    (while (< k (sslength sset))
      (dos_progn k)
      (setq ename (ssname sset k))
      (setq $Handle (cdr (assoc 5 (entget ename))))
      (setq $GUID (Utl_GUID))
      (setq $X (Xda_GetValue ename app "#X1"))
      (setq $Y (Xda_GetValue ename app "#Y1"))
      (setq $Z "0")
      (setq $Value (Xda_GetValue ename app "VALUE"))
      (setq $2D1 (Xda_GetValue ename app "#2D1"))
      (setq dlst (p_PODS-AddValue flst))
      (setq tlst (cons (Lst_List->String (reverse dlst) "\t") tlst))
      (setq cdata (p_PODS-RCount 1 cdata))
      (setq k (1+ k))
    ) ;while
    (Fil_Write fname "w" (cons NIL (reverse tlst)))
    (setq cdata (p_PODS-TCount 1 cdata))
    (dos_progn)
  ) ;progn
  (alert (strcat "Error: Variables missing p_PODS-Export" table))
) ;if
) ;progn
) ;if
(Err_FunctionList NIL)
(setq cdata cdata)
) ;defun
; -----
(if (= (p_ModelCheck) 0) (princ "\n\t... PODS Export"))
(princ)
; ***** <EOF> *****

```