Final Report
April 29

Pipeline Weld Failure Consequence Analysis

SCHULICH
School of Engineering
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ENGO 500 Engineering Project

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Academic Integrity

We, the undersigned, certify that this is our own work, which has been done expressly for this course, either without the assistance of any other party or where appropriate we have acknowledged the work of others. Further, we have read and understood the section in the university calendar on plagiarism/cheating/other academic misconduct and we are aware of the implications thereof.

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Executive Summary

This project's purpose is to analyze the worst case consequences of girth weld failures on pipelines in relation to their rupture radius on the surrounding area. Girth welds are more prone to failure than other parts of the pipeline due to the welding processes used creating a weakness at the joint. Engineers have a responsibility to consider the safety and welfare of the public, the environment, and city infrastructure. The objective of the project is to use provided pipeline and girthweld data to calculate the potential damage caused to both buildings and people for each girth weld within its rupture radius and leak radius using ArcGIS, FME, and Python. The solution should be automated, allowing for multiple data sets to be used when calculating the consequences of the girth weld failure. This project could be applied to plan new pipelines and view their potential risks..

The first part of the project was finding a data set for all of the structures in Calgary and classifying them. This was obtained for free through OpenCalgary and contained approximately 456,000 structures with polygon data, roof surface area, and general building classification codes. Due to the size of the dataset, the team created a 300-meter radius to reduce the classification to 27,000 buildings. Additionally buildings with an area of 500ft^2 were classified as houses (H22). Then through batch classification using ArcGIS the team classified the remaining buildings with some more complicated structures such as apartment buildings, industrial buildings, etc the team used Google Earth, and Google Street View to determine the type of structure.

The team used Feature Manipulation Engine (FME) to create an automated workflow, which involved several processes such as data import, girth weld classification, and valves. The workflow involved reading in the input data, creating buffers, relating classified structures to the buffers, and determining the closest shutoff valve to the specified girth weld. The team encountered difficulties with determining the closest valve as the provided pipeline data had gaps between lines causing discontinuity in the data making the line trace through the pipeline inconsistent.

The team then took the data created by FME that classified buildings to the girthwelds and outputted the data into shapefiles that were then visualized by ArcPro. The final product

produced is able to click on any girthweld and it will highlight all structures in the area and output a table of the total cost of the structures, the number of people affected, and other information. Overall this project was successful and it does what we set out to do. Unfortunately not all of the features that we intended it to have are working completely but it is in a state that does output a majority of the necessary information.

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List of Abbreviations

WFCA	*Weld Failure Consequence Analysis*
APEGA	*Association of Professional Engineers and Geoscientists of Alberta*
GIS	*Geographic Information System*
FME	*Feature Manipulation Engine*
R&D	*Research and Development*
UI	*User Interface*
UE5	*Unreal Engine 5*

List of Symbols

π	*Pi (Approx. 3.14)*
r	*Radius of pipe (for volume calculation)*
h	*Length of pipe (for volume calculation)*

Introduction

The Pipeline Weld Failure Consequence Analysis ENGO 500 project, sponsored by Stantec and advised by Shirley Chan, has been undertaken by Matyas Bakos, Mark De Guzman, Nate Roussel and Tyson Toews under the supervision of course coordinator Dr. Steve Liang. Over the course of the Fall 2022 and Winter 2023 school year, several reports and presentations were produced regarding the project plan, progress, etc. This is the final report of the project, where the culmination of the work done over the last 8 months will be discussed. Context will be provided about the project - its background, importance, and primary objectives. The problem presented will be explored in further detail to gain a better understanding of what was done. The detailed design section will cover the various alternate solutions that were considered based on the problem definition. This will be followed by the results of the project, which will be split into two parts; the first being the schedule results - how the project played out compared to what was envisioned in the planning phase, and the second part regarding the technical results of completing the project itself. The report will conclude with a summary of the results and final thoughts on the project.

Background

Pipelines and their safe operation are crucial in today's society, and everybody that partakes in modern society benefits in some way from pipelines. The dictionary definition of a pipeline is "A long tubular conduit or series of pipes, often underground, with pumps and valves for control, used to transport crude oil, natural gas, water, etc., especially over great distances" [1]. The earliest known use of pipelines date back to 4000 BC where Babylonian settlements were using clay sewer pipes for wastewater management. The Greeks and Romans were also known to use pipelines for storm sewer systems and water supply. Water transportation was the main use for pipelines in these early civilizations [2]. Technological advancement has allowed an expansion of the uses of pipelines in the modern world. During the 19th and 20th centuries, the modernization of homes created the need for water, gas and oil for these homes to function properly. With these advancements, development of stronger pipes and new techniques were required in order to build stronger pipes to be able to push liquids at higher pressure over longer distances. Advancements of pipeline construction over the years have increased drastically, however, as with any new technology, there are some drawbacks.

For the purpose of this project, the main focus is the analysis of pipeline girth weld failures and the effects it has on surrounding areas. A girth weld is a section of a pipeline where two different pipelines have been welded together. Girth welds are more susceptible to failure than other parts of the pipelines, which make them a prime part of the pipeline to be the focus of a project like this. One of the main reasons that these girth welds fail are the welding processes and techniques used to fuse the pipes together. Two examples of welding techniques are uphill and downhill welding. In theory, uphill welding creates stronger joints between the metals but has a higher potential to burn through since the direction of electrode flow is against gravity. Downhill welding takes careful consideration to welding parameters meaning tighter control is required since a slight variance will result in slag inclusions and lack of penetration defects [3]. Another key factor resulting in girth weld failure is the presence of loading that promotes crack growth. Most pipelines are underground, therefore active loading due to external ground movement as well as generated loads from construction affect the weld durability immensely. Careful analysis of the relationship of how these loads affect pipeline integrity is key to prevent any major failures creating unwanted hazards to the environment and the surrounding areas [4]. Other factors that affect girth weld failures include the dimensions of the defects present, the age and material properties of the pipe as well as negligence from workers and human errors. The factors presented above present the problem of how these failures should be analyzed in order to identify potential populations, buildings and roads that could be impacted due to girth weld leaks or ruptures.

Importance

As engineers, the foundations of our duty is rooted upon integrity, competence, dignity, and devotion to service. Under the APEGA code of ethics, the first rule of a professional engineer is the consideration of the health, safety and welfare of the public, including themselves, and have regard for the environment. Additionally, engineers must uphold and enhance the reputation of their professions and the ability of these professions to serve the public interest [5]. With the problems discussed regarding girth weld failures, engineers have a duty to prevent these issues from occurring. It is also important for engineers to have an understanding of the possible damage if things go wrong, which this project will show.

Pipeline operations improve society and the quality of life of those living within by providing resources that stimulate daily life. With this in mind, engineers (and other professionals) should always prioritize the safe operations of pipelines in urban and rural areas to best serve the communities interest. As with all man-made creations, perfection is unachievable therefore complications are inevitable. Analyzing the root cause and the potential effects of these problems is essential in operating and regulating the many hazards of pipelines. Through the use of leak hazard radii and rupture impact radius, the number of injuries and cost of damages from the girth weld failure can be estimated. Development of an automated system through detailed inspection of pipeline leak and rupture data fulfills an engineer's due diligence in identifying a problem and using information that help prevent similar events from happening in the future. In the industry, the project could potentially be applied to identify higher risk girth welds that should be monitored closer than others. This can prevent girth weld failures and avert disasters.

Objectives

At a high level, the main objective of this project was to use the data provided to calculate the damage done in the case of girth weld failure. This was to be accomplished using software such as ArcGIS, FME, and/or Python. The solution should be automated to save on time and cost. This would allow for similar data to be put into the program and perform the analysis. Analysis can be performed on a yearly basis, as is described in the project descriptions. It could also be applied to other cities.

Problem Definition

Project Summary

The main goal of the *Pipeline Weld Failure Consequence Analysis* is to analyze the consequences of a girth weld failure, particularly a rupture or leak. Affected populations and structures must be identified for girth welds. To help accomplish this, six datasets were provided at the start of the project:

1. Pipelines - The pipelines themselves. Downloaded from the Alberta Energy Regulator website (data scrubbed and renamed). The dataset includes:
   - Pipeline owners.
   - The outside diameter of the pipeline.
   - The substance being transported in the pipeline (Natural Gas, Low Vapourized Products, etc.).
   - The length of the pipeline.
2. Girth Welds - Points along the pipelines representing girth welds. For the purpose of this project, they will be randomly generated. These include:
   - Their respective pipelines company, diameter and substance carried.
   - Leak Hazard Radius for injury and Component Damage.
   - Rupture Impact Radius.

3. Valves - Points on the pipe representing valves that can be used to control the flow in a pipe. Like the girth welds, these will also be randomly generated. These will be used to calculate the volume of product lost when a girth weld fails.
4. Dwellings - Point representations of dwellings/single family homes (incomplete dataset).
5. Structures - Polygon representations of buildings, parks, churches, etc. (incomplete dataset).
6. Structure valuation - Contains dollar values and average number of occupants inside and outside of structures. This data will be used to calculate the damage done when a girth weld fails based on the types of structures or dwellings in the area.

Note that the dwellings and structure datasets are incomplete. This will be addressed later in the "Functional Requirements" section. Apart from these two datasets, all of the necessary data to complete the project was provided. For the purpose of this project, analysis will only be done in Calgary, however, an automated solution can be used in different areas.

Figure 1 below shows datasets 1-5 loaded in ArcGIS Pro. Figure 2 shows a zoomed in view on a specific area with some structures, and finally, figure 3 is a screenshot of the structure validation sheet.

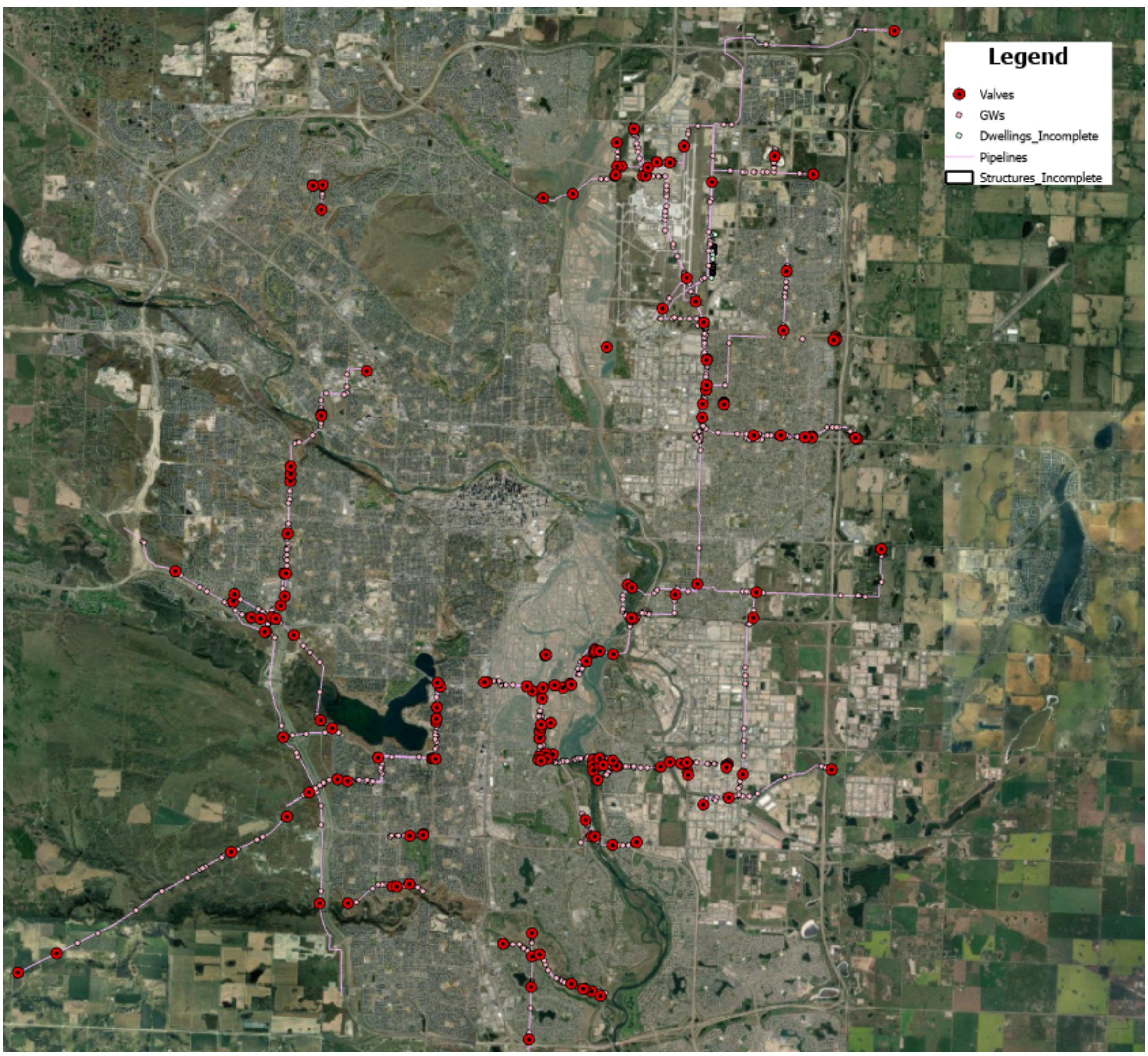


Figure 1: Calgary With Pipeline, Girth weld, and valve data

Figure 2: Map From Figure 1 Zoomed in to Shows Examples of Dwellings (Points) and Structures (Polygons)

Structure Type Code	Description	Structure Value ($)	Avg. # Occupants (Inside)	Avg. # Occupants (Outside)
A5-	Small apartment building < 5 stories	4518000	25.992	1.368
A5+	Concrete apartments ³ 5 stories	47848500	162.45	8.55
Outdoor Recreation Area	Inside Park	18600	0	2.97
Campground	With trailer parking	1500000	16	16
Church	Church	1312125	4.212	0.468
Com	Commercial building, 10-20 times the area of a house e.g. strip malls	2713250	12.019	2.121
Com L	Large commercial building, large malls, warehouses, etc.	22640000	91.834	16.206
Com S	small business, restaurant, etc.	566000	14.6455	2.5845
Ind.	Industrial building, same size as Com e.g. non-retail bays	2688250	11.9795	0.6305
Ind. S	Industrial building, small	268825	1.19795	0.06305
Ind. L	Industrial building, same size as Com L, e.g. large plants	20349375	427.5	22.5
H22	House	269868	2.166	0.114
TW L	Townhouse Complex	3439350	43.32	2.28
TW S	Townhouse Complex	859837	10.83	0.57
sdH	Semi-detached house	359825	4.332	0.228
School	High school	14421750	176.477	31.143
Golf Course Club House	Golf Course Club House	339600	0.684	3.298
Community Centre	Also arena, small inside	6560625	8.541	0.949
Sr. Citizen's Home	Sr. Citizen's Home	11295000	93.7365	4.9335
Correctional Institution	Correctional Institution	15456000	278.6635	14.6665
Hospital	Hospital	137160000	772.2	7.8
Hotel	Hotel (including built-in café)	27342000	40.05865	2.10835
College / University	College / University	43265250	626.1865	110.5035
Daycare	Daycare	566000	10	2

Figure 3: Structure Valuation Spreadsheet

Functional Requirements

At each girth weld, the following questions must be answered:

1. How many people are affected in the Leak Hazard radius for Injury?
2. How much structural damage can happen in the Leak Hazard radius?
3. How many people are affected in the Rupture Impact Radius?
4. How much damage can happen in the Rupture Impact Radius?
5. How much volume of product is in the network with the affected girth weld?

The following is a summary of tasks for completion:

1. Completing the structures and dwellings dataset - incomplete datasets were provided, they must be completed. The objective is to end up with a dataset of all the structures and dwellings that could be affected by girth weld failure.
2. Classifying the structures and dwellings - each structure had to be classified into one of the categories on the structure valuation sheet (Figure 3)

3. Determine the structures and dwellings affected by girth weld failures - this was to be done using the radii from the girth weld data along with the completed building datasets.
4. Using the identified buildings and the structure valuation, the damage (monetary and human) will be calculated for all three radii (questions 1-4).
5. The upstream and downstream valves from the girth weld will be identified and the distance between them calculated and/or measured using GIS.
6. The volume of product lost between the valves will be calculated using the standard volume formula:

   $V = 2 * \pi * r * h \ldots \ (eq.\ 1)$

   $r = radius\ of\ pipe\ (from\ pipeline\ data)$

   $h = length\ of\ pipe$

When a girth weld fails, the upstream and downstream valves will be shut off, and the product between the valves is lost.

This solution should be automated. A user would be able to click on a girth weld and all of these calculations could be done automatically and provide the user with the total damage done if leak or rupture, what structures are affected, and how much volume is lost.

A few things that could be done in this project or a similar project that will not be done (out of scope) are listed below:

- Calculating the environmental impacts of the girth weld failure (this project will only deal with structural and human damage).
- Only the volume of product lost when a girth weld fails will be calculated. The monetary value of the lost product will not be.
- The elevation of the girth weld won't be accounted for. For example, a girth weld on top of a hill may have bigger leak hazard radii due to the product running down the hill. Such scenarios will not be considered in this project. In other words, this is a two dimensional project, rather than three.

- The group will also not look into steps for mitigating the girth welds failure.
- Any action to be taken after the theoretical girth weld failure, such as cleanup or repair is also out of the scope of this project.

Deliverables

The main deliverable of the project is an automated system where human population and building damages can be calculated in the event of a girth weld failure. It should also automatically detect damages and create a list of affected buildings in a shapefile and excel file for both visual representation and simple number viewing and it should show the costs associated to each building or affected person. This allows a fully automatic system where the input is the size of the leak radius, pipelines, girth welds, valves, and structures. It should also visualize the extent of the leak and the damaged buildings. This report can be used to identify which girth welds should be inspected or have maintenance done on them the most often.

Multiple reports and presentations that must be submitted for grading for the ENGO 500 course. These included a project plan, design review, progress report, and the final report/presentation.

Constraints and Assumptions

Constraints and assumptions that were identified for the project.

Some of the assumptions are:

1. Only a 2D radius around the leak is needed.
2. Human life is valued at 12 million dollars.
3. The oil flow is constant.
4. If oil touches a building it is considered to have maximum damage done to it.
5. Everything is assumed to be a worst case scenario.
6. Greenery costs are not taken into account.
7. Effects on the ecosystem are not taken into account.
8. Product loss is not accounted for
9. Effects on groundwater are not taken into account.

10. All data and satellite imagery are assumed to be up to date and accurate.
11. All structures with a certain code are assumed to have the same cost (homes can greatly vary in price, for the purpose of this project, they are assumed to be $268 868).
12. Only the volume of product lost will be calculated (not monetary value).

Some of the constraints are:

1. Done using arc GIS, arc map. FME, python or other software that is freely available to the university due to a low budget.
2. The project will have to be done by the end of the school year (late April 2023).
3. Only four of us are working on the project.
4. Project has to be done on top of other classes.
5. Budget is low so open data sets need to be used.
6. The project may have to be put on hold to write reports for the class.
7. FME, arcGIS and Python are not collaboration friendly, ie. only one person can work on them at a time.

Detailed Design

Data Set Acquisition

Stantec provided five main datasets consisting of:

- Pipelines (shapefile)
- Girth Welds (shapefile)
- Valves (shapefile)
- Incomplete Structures and Dwellings (shapefile)
- Structure Valuation (.xlsx)

The incomplete structures and dwellings dataset were not used for this project as it consisted of points rather than polygons. A reliable structures and dwellings dataset is essential in order to produce successful results. Each member set out in finding a dataset containing all the dwellings data for the City of Calgary. There were various datasets found on Open Calgary, however a particular Alberta Structures GeoJSON file was obtained containing required metadata such as:

- Polygon information for each building.
- Location for each building using the NAD83 Alberta 3TM 114 W map projection.
- General building code. E.g residential roof outline, commercial roof outline, etc.
- Area of each building footprint.

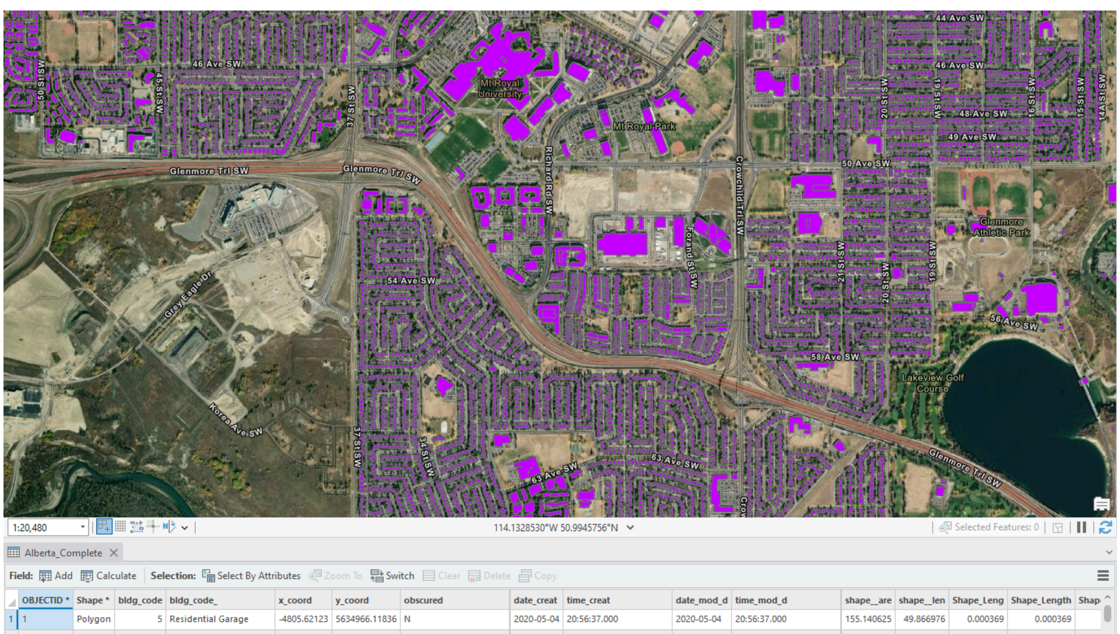


Figure 4: Complete Alberta Structures

Data Classification

The data acquired consisted of approximately 456 000 structures. It was unrealistic to classify the whole dataset since pipelines only run across specific portions of the city. For this reason, a 300 meter radius was created with each girth weld reducing classification to 27 000 buildings. During the classification process, buildings with the code *Residential Roof Outline* were assumed to be homes (H22). This allowed the group to classify the remaining buildings. Some structures were easily determined through Google Maps satellite imagery and batch classified in ArcGIS. However, other buildings required closer inspection, which was completed through Google Earth or Google Street View for a 3D representation of the structures for a more accurate classification.

Automated Workflow Development - FME

Since the datasets to be used are of various file types such as (.xlsx, .shp), the team decided to use the geodatabase provided by Stantec. This geodatabase was then connected to an ArcGIS Pro project and an FME workspace. Various transformers in FME were used such as *LineCombiner, Aggregator, Snapper,* and *AnchorSnapper* to improve the linear network of the pipelines, however there was minimal change even with the use of these transformers. Due to this setback, a cascading effect was implemented for the *ShortestPathFinder* transformer in order to improve results, which it successfully did. The cascading effect revolved around the idea of taking all failed girth welds and reiterating it with the same process, but with a higher snapping tolerance. Increasing the snapping tolerance improved results, however the team had decided to cease the cascade as the snapping tolerance was snapping into items that were not close to it, producing inaccurate results.

The workflow development can be summarized into 4 main categories:

1. Data Import

   The workflow automation begins through the *Reader* transformer where the user is able to:

   a. Load in the required input data files consisting of:
      i. Girth Welds data
      ii. Shutoff valves data
      iii. Pipelines data
      iv. Structures valuation data
      v. Classified structures data

2. Buffers

   The girthweld data provided by Stantec included 3 main radii:

   a. Rupture impact radius
   b. Leak hazard radius for injury
   c. Leak hazard radius for component damage.

   Through the *Bufferer* transformer each radius were created and exported as a shapefile:

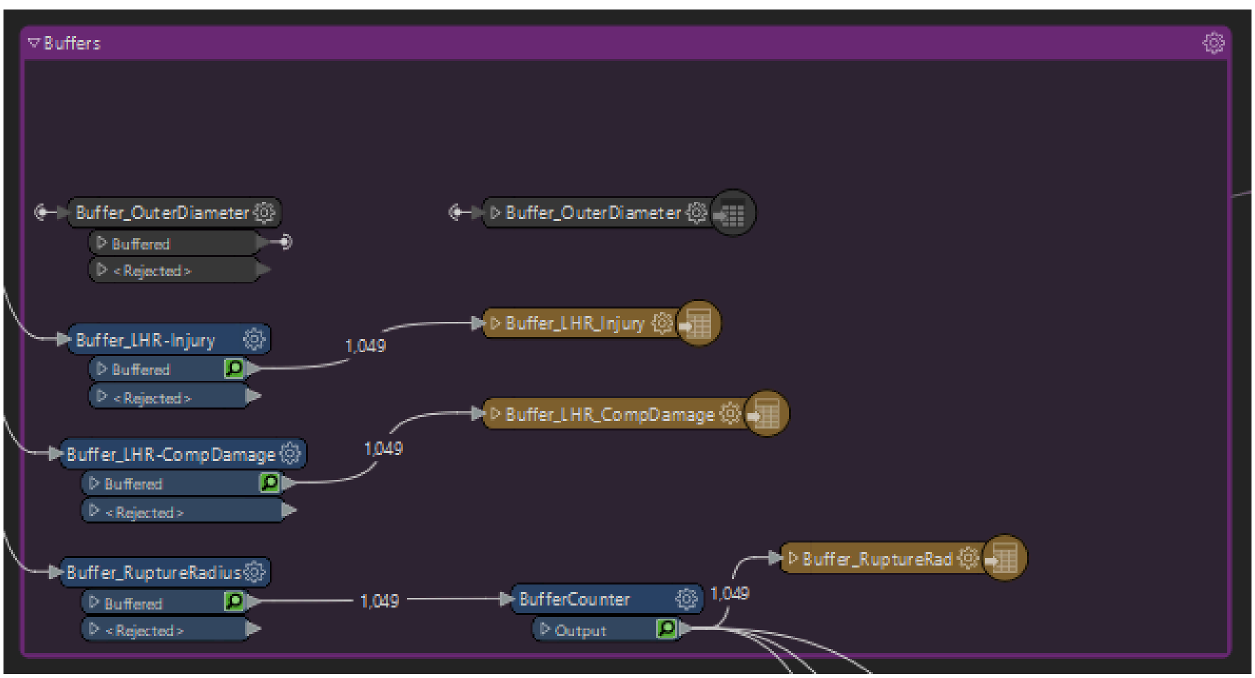


Figure 5: FME Workflow - Buffer Section

3. Structures

With the classified structures, figuring out which structures intersect with each buffer was the next step. There were various transformers used in collaboration with one another, but the two key transformers for this section were the *SpatialRelator and StatisticsCalculator*.

a. The *SpatialRelator* transformers duty is to relate the created buffers created from Figure 5 and relate them to the classified structures data. The *requestor* in this case is the radii and the *supplier* is the classified structures data.

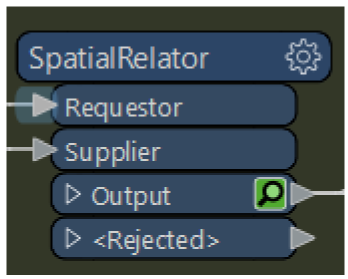


Figure 6: FME Workflow - SpatialRelator Input

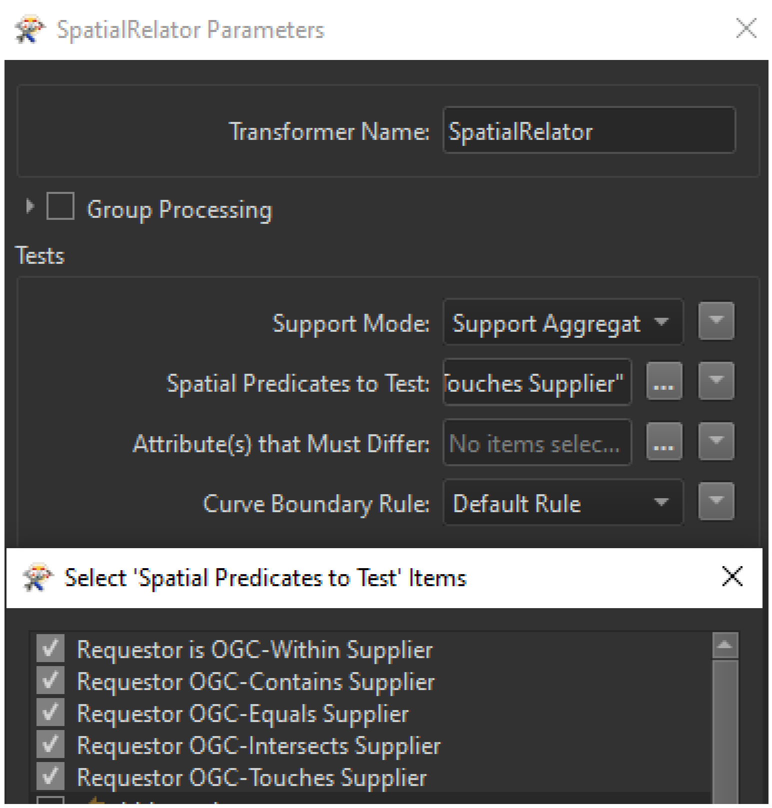


Figure 7: FME Workflow - Spatial Relator Specifications

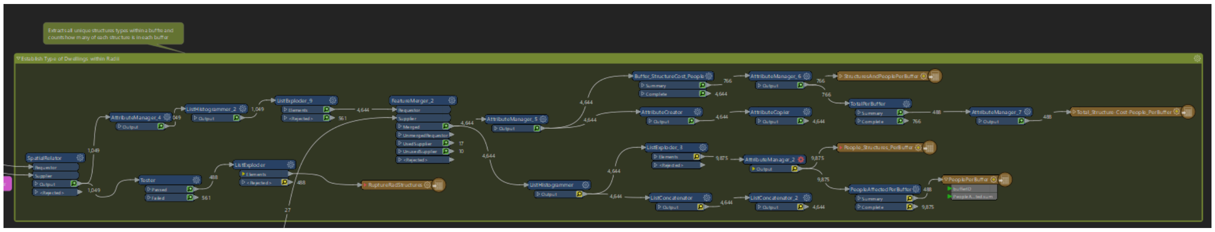


Figure 8: FME Workflow - Buffer Structure Section

b. The *StatisticsCalculator* transformer results are then written onto an .xls file, of statistics for each input such as the number and type of structures and people affected in each buffer. These excel files use data analytics on concerns such as the most expensive rupture area, the girth weld with the highest effect on inside and outside occupants and the area with the most structural damage.

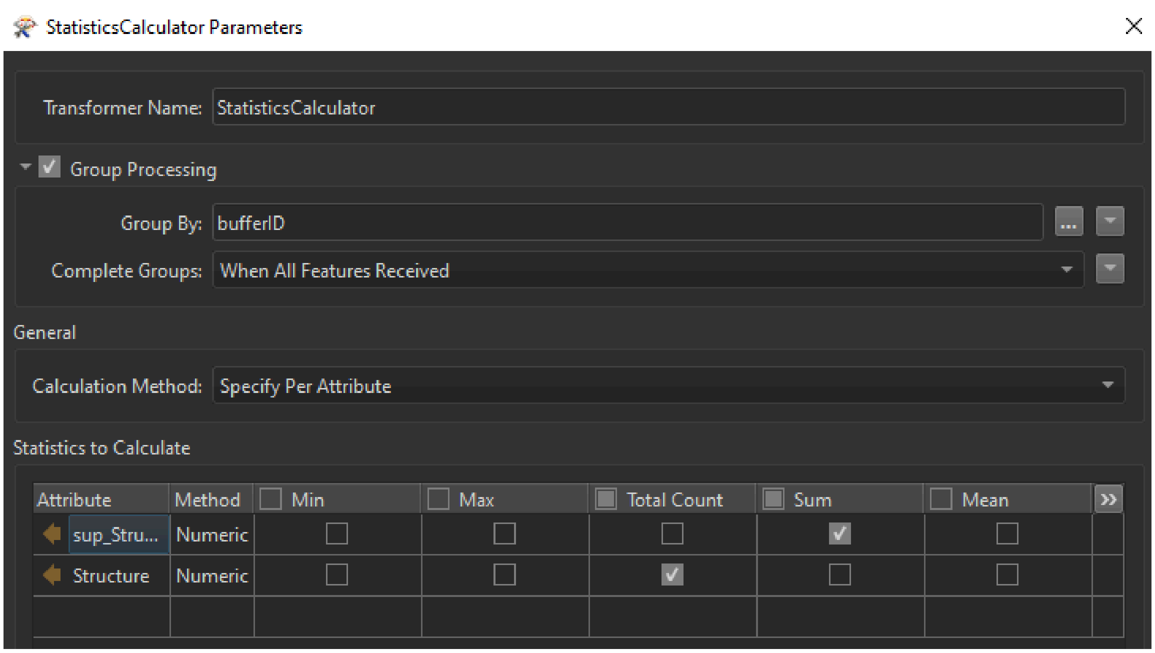


Figure 9: FME Workflow - StatisticsCalculator Example Specification for Structure Statistics

In Figure 9, sup_Stru.. Is the structure value used to sum up total costs, and structure is the structure types used to count structures in each buffer.

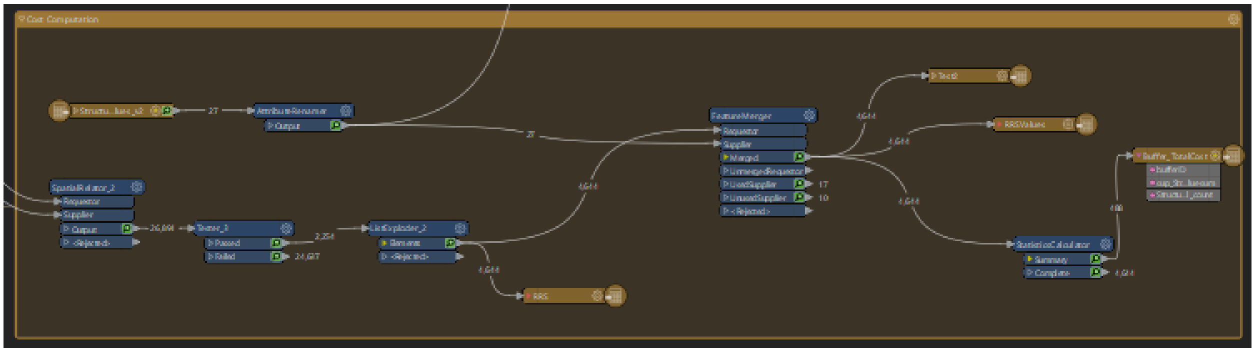


Figure 10: FME Workflow - Affected Structures and People Computation Section

4. Valves

The valves section can be divided into two main sections:

a. Shutoff Valve Determination

i. This task focuses on finding the closest shut off valve to the specified girthweld. Various transformers were in collaboration with each other however the *NetworkTopologyCalculator* and *ShortestPathFinder* transformers were key.

ii. The *NetworkTopologyCalculator* transformer identifies connected lines and outputs a list of related relationships. Since the pipeline data has various discontinuities, therefore the pipeline data was used as an input to find line segments that may potentially be from the same line network. This transformer uses geospatial location of the endpoints of the lines as well as common attributes in its metadata.

iii. Once the pipeline data was connected, the *ShortestPathFinder* transformer was used in order to relate each girth weld and valve to a unique pipeline segment. This was completed by relating each girth weld to each valve in its line segment. The ShortestPathFinder only accepts line segments in the *From-To* input therefore each girthweld has a line for each related valve. The reason for this is the transformer uses the endpoints of the *From-To* line and finds the shortest path within the line segment from the *Network* input.

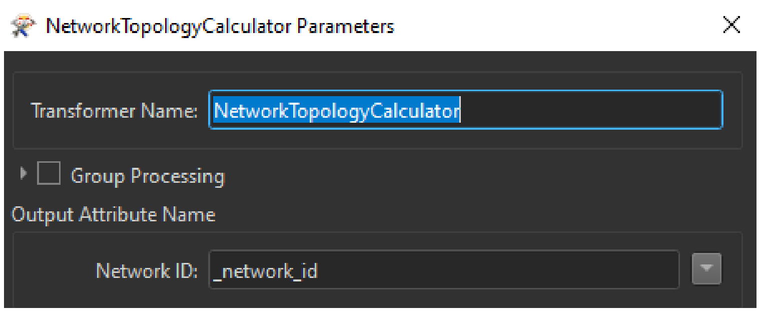


Figure 11: FME Workflow - NetworkTopologyCalculator Specifications

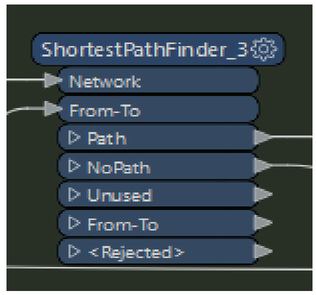


Figure 12: FME Workflow - ShortestPathFinder Inputs

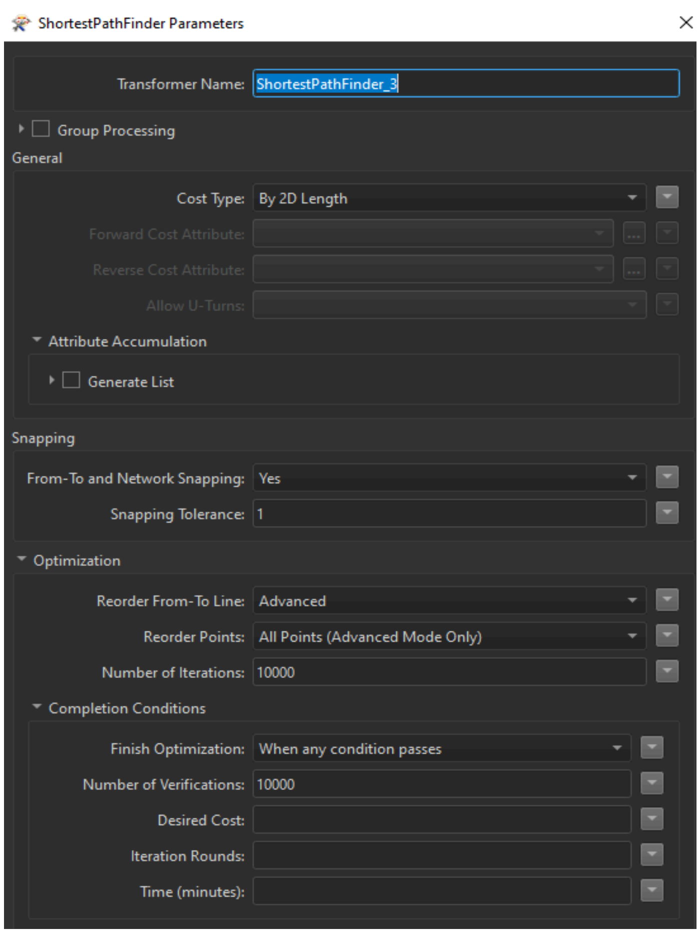


Figure 13: FME Workflow - ShortestPathFinder Example of the First Cascade Specifications

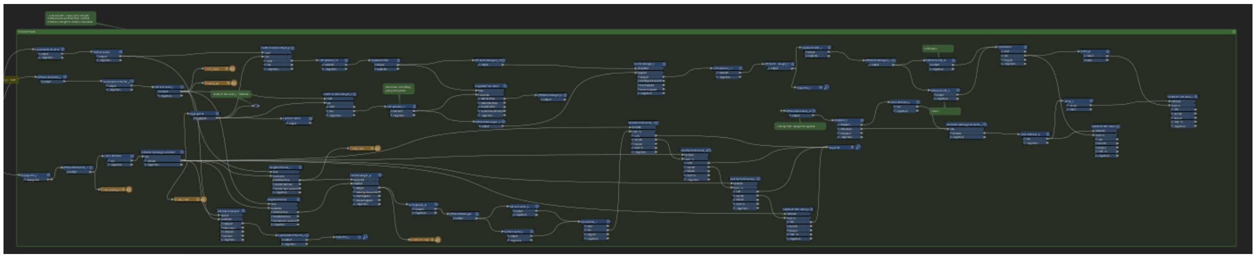


Figure 14: FME Workflow - Shutoff Valve Determination Section

b. Volume of Product Calculation
   i. This task was unsuccessful and not attempted since good results are required from the shutoff valve determination section.

   *more information in **Results** section*

Data Visualization - ArcGIS Pro

Data Integration

As mentioned earlier, the required shapefiles were created from the FME workflow and saved directly into the shared geodatabase. This allowed for easy integration between FME and ArcGIS Pro. One thing to note regarding moving files between FME and ArcGIS is that relationships do not transfer between softwares with files.

Feature Selection

The group agreed on a final visual representation that allows the user to select a girthweld and from that selection, the following is highlighted:

- Rupture impact radius
- Leak hazard radius for injury
- Leak hazard radius for component damage
- Structures affected
- Pipeline segment of the chosen girthweld
- Nearest shutoff valve for the chosen girthweld

Relations between attributes do not carry over from FME, and are re-established in ArcGIS.

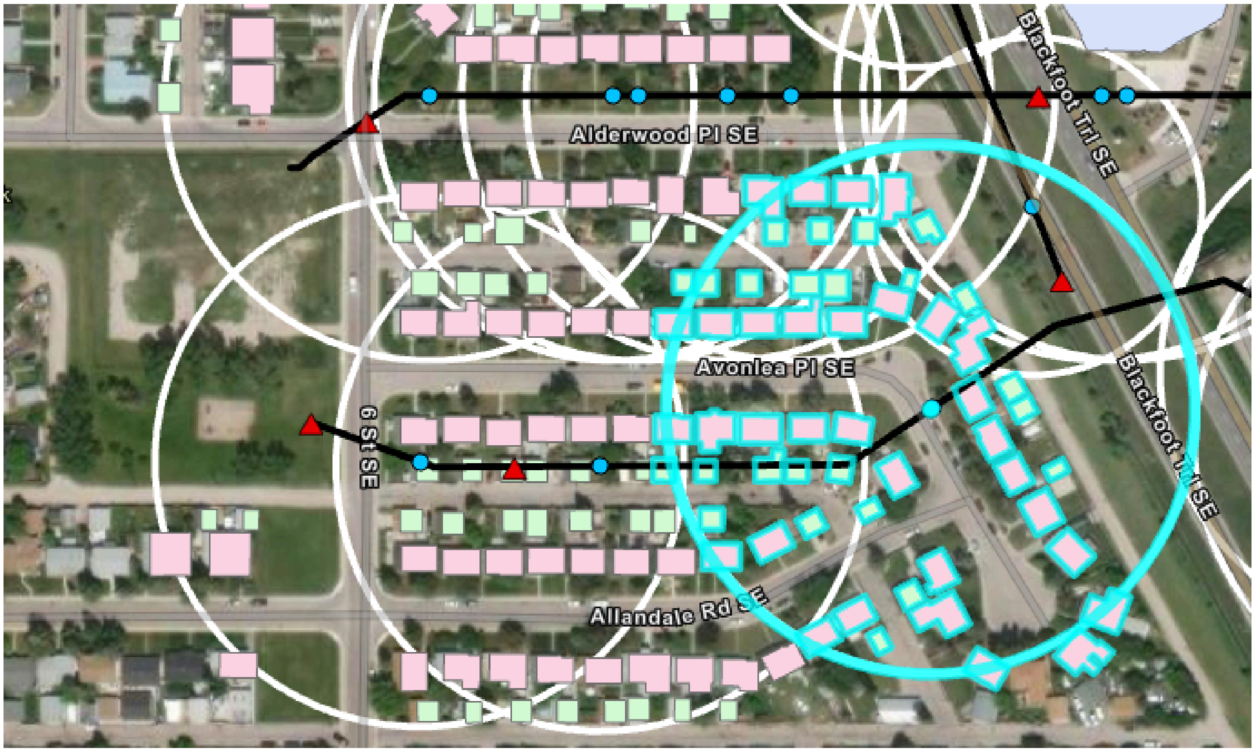


Figure 15: ArcGIS - Feature Selection

Pop-up Customization

On top of the user visualizing the buffers and affected infrastructure, a pop up window of all important information was included to display the following:

- Girthweld ID
- Types of structures affected in the rupture radius
- Number of each structure that would be affected
- Cost of structural damage
- Number of people that would be affected

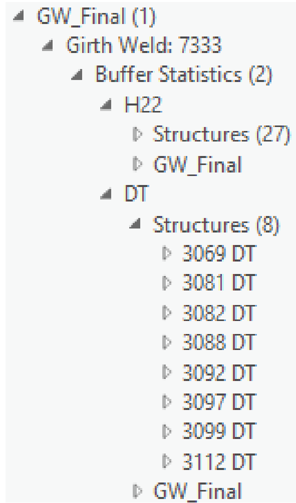


Figure 16: ArcGIS - Pop-Up Example for the Selected Features on Figure 15

Alternative Design

Alternative Solutions

Five problems have been identified at this stage of the project.

1. Obtaining Dwellings and Infrastructure data
2. Identifying Affected Infrastructure
3. Calculating Cost of damages and injury to bystanders
4. Which software would best suit the project?
5. What Display Strategy would best suit the project?

Decision matrices with various factors for each problem were considered to assist with deciding which solution would best fit the problem and the outlined design parameters. All 5 decision matrices can be found on the following page.

Table 1: Dwellings and Structure Decision Matrix

Obtaining Dwellings and structure data	Data Completeness	Data Accuracy	Efficiency	Cost	Total
From Publicly Sourced Data	1	3	3	3	10
Manually using google maps and topo maps	3	1	1	3	8
Private data sources	2	3	2	1	8

Table 2: Affected Infrastructure Decision Matrix

Identifying affected infrastructure	Efficiency	Complexity	Adaptability	Total
Draw impact radii and locate affected infrastructure using buffers	2	1	2	5
Draw impact radii and locate affected infrastructure manually	1	2	1	4

Table 3: Damage and Injury Cost Decision Matrix

Calculating damage and injury cost efficiently	Efficiency	Complexity	Adaptability	Presentability	Total
Establish tool on ARC to automate calculation	3	1	3	3	10
Export data from ARC and post process it using a spreadsheet	2	3	1	3	9
Assign codes and tally up damaged areas manually	1	3	1	3	8

Table 4: Software Decision Matrix

Software Choice	Accessibility	Processing Power	Utility	Knowledge Base	Total
ArcGIS	2	3	3	3	11
QGIS	3	1	1	3	8

Table 5: Display Strategy Decision Matrix

Display Strategy	Accessibility	Complexity	Presentability	Cost	Total
Google Earth	3	3	2	3	11
ArcGIS	1	3	1	2	7
Web Tool	2	1	3	1	7

The idea of using Unreal Engine 5 was also discussed early on in the project, however this was removed due to its complexity. Python scripting was also removed as the team had decided that ArcGIS and FME were well equipped with the necessary tools to complete the project.

Results

Scheduling Results

This section will go over how closely the team followed the schedule created during the project planning phase. All of the work packages were assigned to seven different general categories and given lengths and dates. Based on this, the following Gantt Chart was developed (shown in Figure 21). The critical path is shown in red.

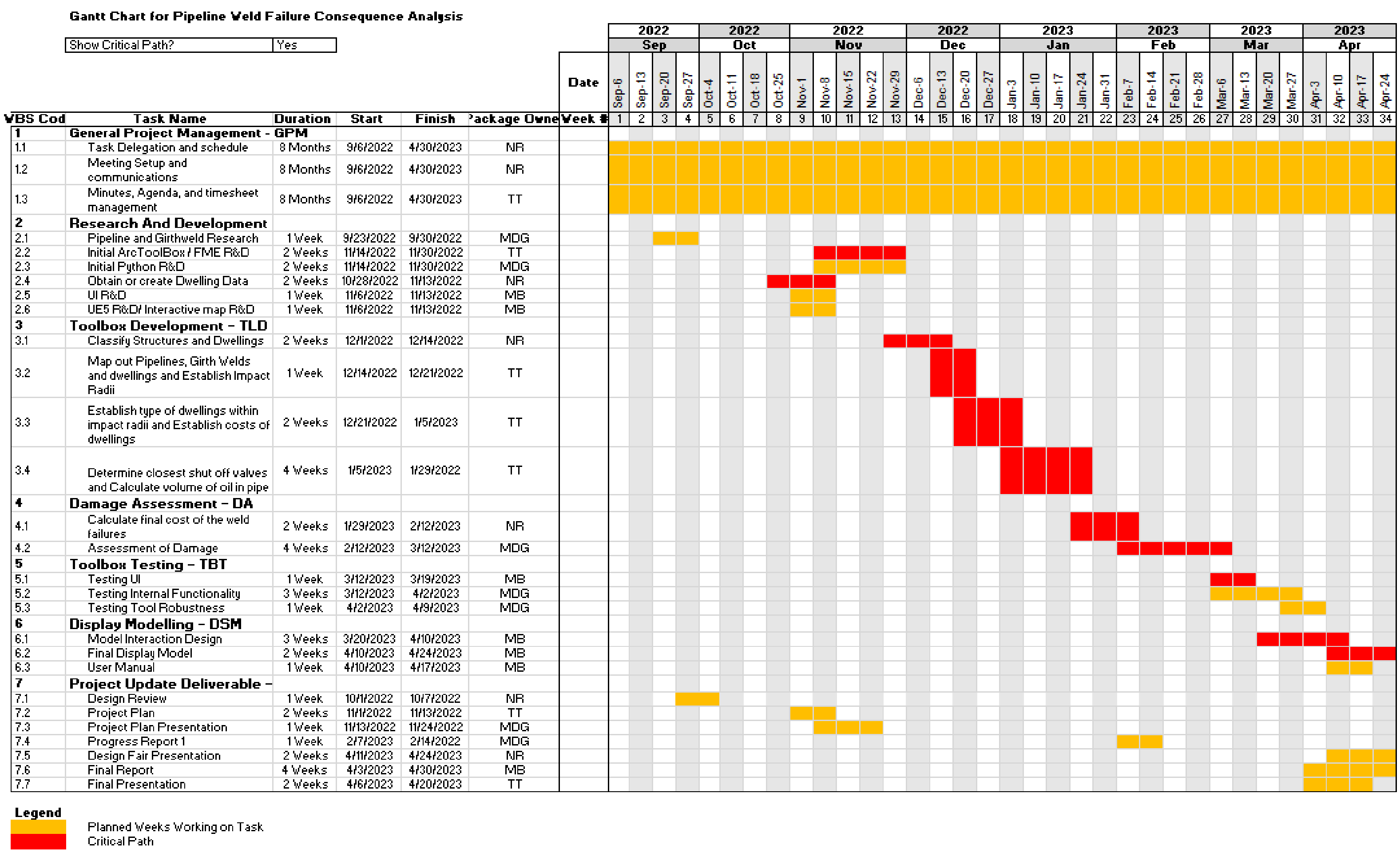


Figure 17: Gantt Chart Created in Project Planning Phase

At the end of the project, updating the Gantt chart to show the actual times that the tasks were worked on and any updates results in Figure 18 below, where orange represents the original schedule, purple represents the actual schedule, orange/purple is crossover between the two, and red is canceled tasks.

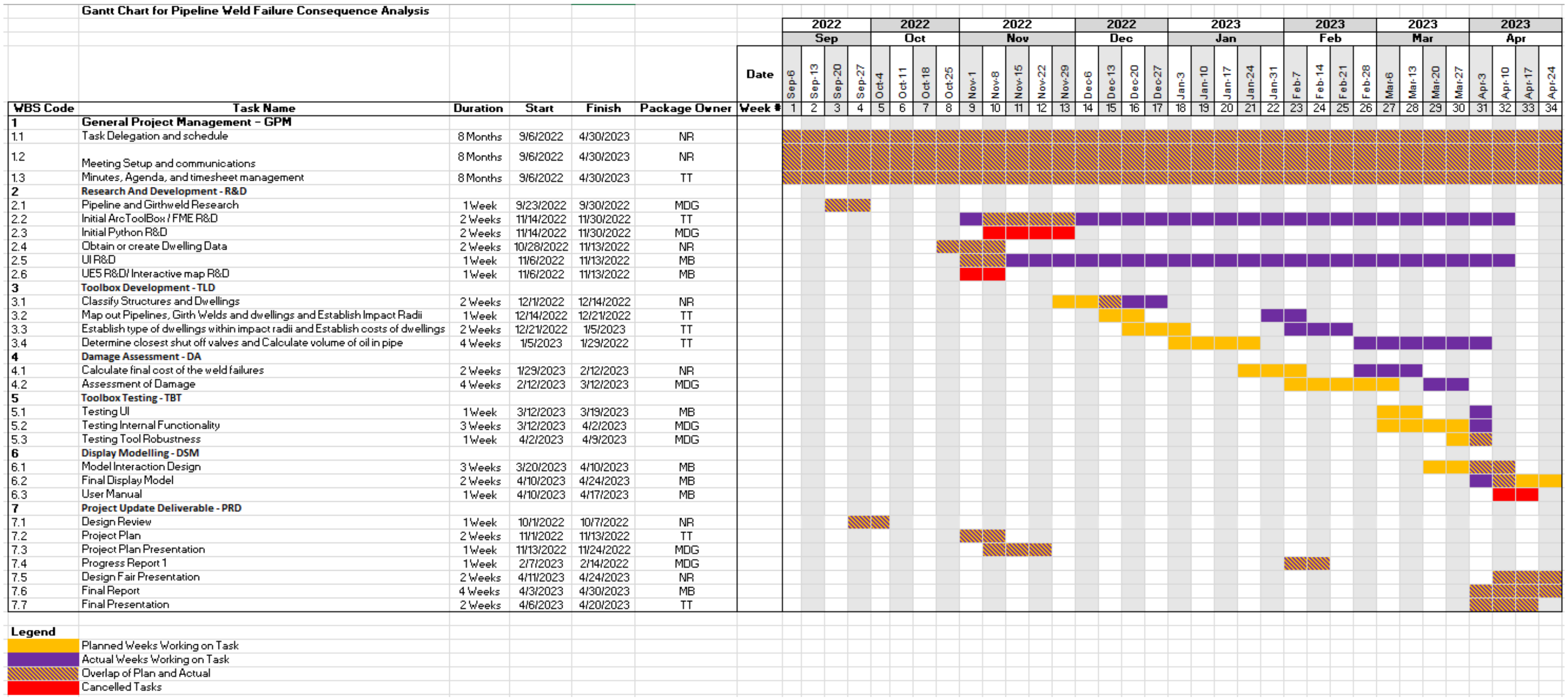


Figure 18: Updated Gantt Chart at End of Project

Looking at Figure 18, we can see that there were multiple changes to the project and its tasks compared to the original plan in Figure 17. First, the ArcToolbox and UI R&D was expanded for most of the project. Since the group was exploring new softwares and tools, R&D was ongoing rather than a set duration task. The initial Python R&D was canceled, as later in the project, the group came to the conclusion that the project could be completed without Python. Similarly, Unreal Engine 5 R&D was also canceled, as it wasn't necessary. The final canceled task was one to create a user manual. This was deemed unnecessary, as at least one group member would be present at all times at the design fair to explain the project. It was cut off when the project fell behind schedule. Apart from that, most of the changes made to the schedule were delays due to the project being behind schedule. Some tasks were shortened or made longer. Determining the closest shutoff valves and calculating volume of product lost proved to be a much more difficult task than initially thought; it was worked on for longer than planned. On the other hand, the testing tasks and display tasks were shortened. Although it would have been good to have a more user friendly display for the guests at the design fair and to have tested the solution more thoroughly, these were shortened to make time for FME tasks that complete the objectives of the project.

Overall, the majority of main objectives of the project were completed. Being behind schedule resulted in aesthetic tasks to be shortened, which resulted in a less feature rich end product in ArcGIS.

The initial and final Gantt charts can be found here: GanttChart.xlsx. Note that due to issues with importing the charts to google drive, the color for actual/planned crossover is changed to blue.

Project Results

Structure data acquisition and classification was successful. The main sections where the success of the project shows is through the Automated Workflow completed through FME and the Data Visualization completed in ArcGIS.

The four main sections of the workflow design correspond directly with the data visualization aspect of the project. The results are mainly evident through ArcGIS since FME acted similar to how the backend of a web application is and ArcGIS is the frontend.

From the provided Stantec data, all files were loaded into ArcGIS. All additional attribute manipulation and additional shapefiles coming from FME were added.

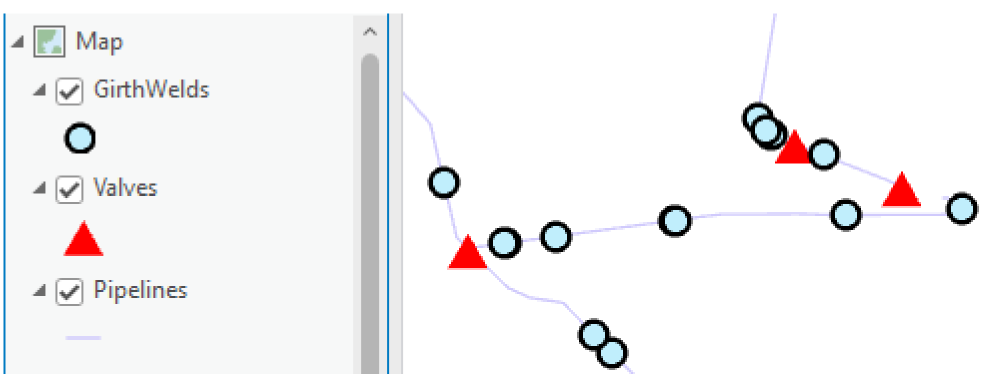


Figure 19: ArcGIS - Provided Data Visualization

Once the automated workflow is run , it will create all the specified shape files (rupture buffers, and affected infrastructure) into the geodatabase. Figure 20-22 is the output of the *Buffer* section in the FME workflow.

Figure 20: ArcGIS - Rupture Impact Radius

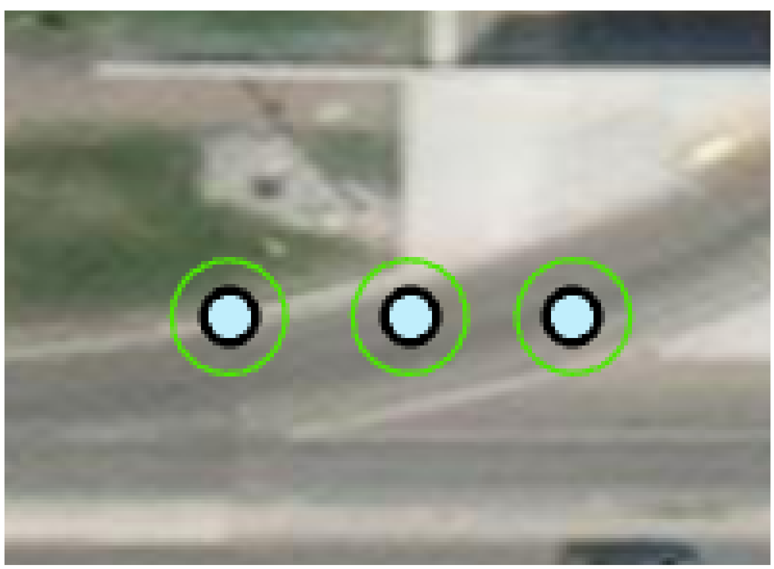


Figure 21: ArcGIS - Leak Hazard Radius for Injury

Figure 22: ArcGIS - Leak Hazard Radius for Component Damage

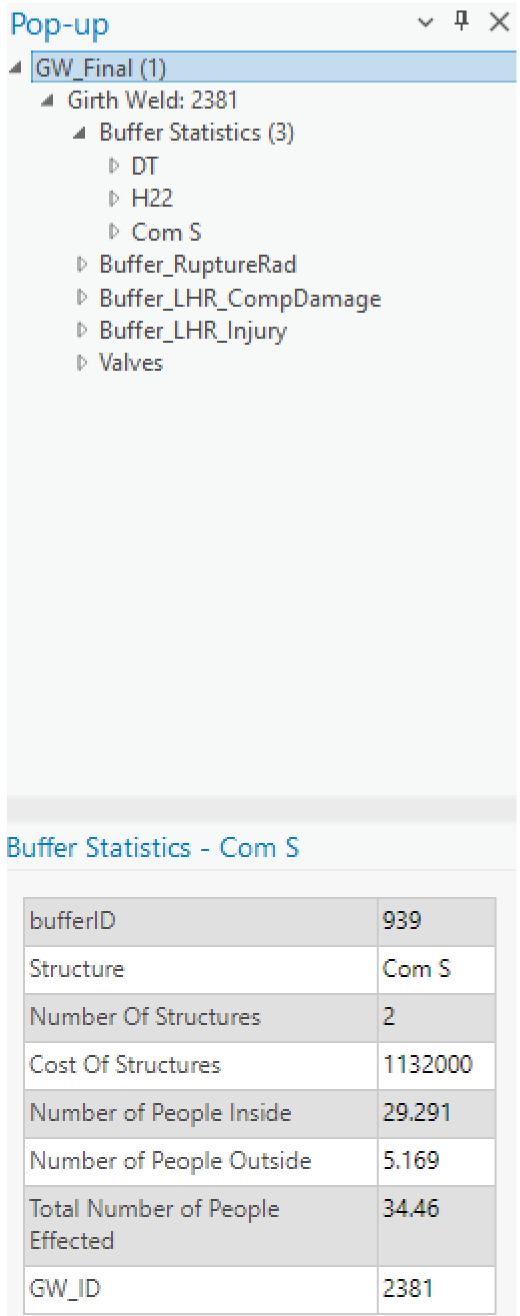
As mentioned in the data classification section of the design, Figure 23 shows the structures that fell within the 300 meter buffer for classification. The complete dataset shown in pink was disregarded and a new shapefile in yellow was created with the classified structures.

Figure 23: ArcGIS - Complete structures (Pink) and Classified Structures (Yellow)

As the FME workflow was being developed, everything was being tested simultaneously to ensure all pieces were working as they should. The feature selection shown in Figure 24 highlights all three radii, the affected structures and the selected girthweld

Figure 24: ArcGIS - Feature Selection Result

Based on Figure 24, the pop-up that appears for the user shows all relevant information about the selected girthweld including the girthweld ID, bufferID, the nearest shutoff valves, and structures in the buffer and the people affected in the buffer. The relationships between each selected feature was through attribute manipulation in FME and relates in ArcGIS.



bufferID	939
Structure	Com S
Number Of Structures	2
Cost Of Structures	1132000
Number of People Inside	29.291
Number of People Outside	5.169
Total Number of People Effected	34.46
GW_ID	2381

Figure 25: ArcGIS - Pop-Up for Selected Girth weld and Com S structure type in Figure 24

Originally, the team had decided on presenting this information in a different manner, however due to time constraints during the data classification delay, the built-in ArcGIS pop-up extension was used as shown in Figure 25.

Through the FME workflow, excel files were created for data analytics. The excel files are used in determining the cost and number of people affected in each buffer/girthweld. Figure 29 comes from the values in the excel file in Figure 26. Figure 27 is an example of the damage cost and injury information that can be extracted from each girth weld.

	A	B	C	D	E	F	G	H
1	bufferID	Structure Type Code	NumberOfStructure	CostOfStructureDam	InsideOccupantsAV(	OutsideOccupantsA\	PeopleAffected	GW_ID
2	4	H22	4	1079472	8.664	0.456	9.12	6748
3	4	H22	4	1079472	8.664	0.456	9.12	6748
4	4	H22	4	1079472	8.664	0.456	9.12	6748
5	4	H22	4	1079472	8.664	0.456	9.12	6748
6	18	Com S	1	566000	14.6455	2.5845	17.23	7903
7	18	Com S	1	566000	14.6455	2.5845	17.23	7903
8	18	Com S	1	566000	14.6455	2.5845	17.23	7903
9	18	Com S	1	566000	14.6455	2.5845	17.23	7903
10	19	Com S	1	566000	14.6455	2.5845	17.23	4171
11	19	Com S	1	566000	14.6455	2.5845	17.23	4171
12	19	Com S	1	566000	14.6455	2.5845	17.23	4171
13	19	Com S	1	566000	14.6455	2.5845	17.23	4171
14	20	Com S	1	566000	14.6455	2.5845	17.23	1193
15	20	Com S	1	566000	14.6455	2.5845	17.23	1193
16	20	Com S	1	566000	14.6455	2.5845	17.23	1193
17	20	Com S	1	566000	14.6455	2.5845	17.23	1193
18	21	Com S	1	566000	14.6455	2.5845	17.23	7555
19	21	Com S	1	566000	14.6455	2.5845	17.23	7555
20	21	Com S	1	566000	14.6455	2.5845	17.23	7555

Figure 26: Excel Sheet for Each Structure Within Each Buffer and the Number of People Affected

	A	B	C	D	E
1	bufferID	TotalCostOfStructur	TotalNumberOfPeo	GW_ID	TotalNumberOfStru
2	4	1079472	9.12	6748	4
3	4	1079472	9.12	6748	4
4	4	1079472	9.12	6748	4
5	4	1079472	9.12	6748	4
6	4	1079472	9.12	6748	4
7	4	1079472	9.12	6748	4
8	18	566000	17.23	7903	1
9	18	566000	17.23	7903	1

Figure 27: Excel Sheet for Total Costs and the Number of People Affected in Each Buffer

Looking back at Figure 4, we can see that there are 3 green triangles highlighted. The shutoff valve task was a major concern in this project as finding a proper solution relating the girth welds and valves to the pipelines was challenging. Additionally, the workflow should only identify one upstream and one downstream valve per each selected girthweld. There are 1049 unique girth welds and the team was only able to achieve about 605 successful outputs, putting the success rate at just over 57%. With the 605 successful outputs, not all results were correct, however it is difficult to quantify these values, however Figure 24 is an example of an incorrect result as there are 3 chosen valves even though the expected result is 2. In Figure 27, the first iteration only 12 girth welds pass, however, with each new iteration, additional girthweld solutions are achieved.

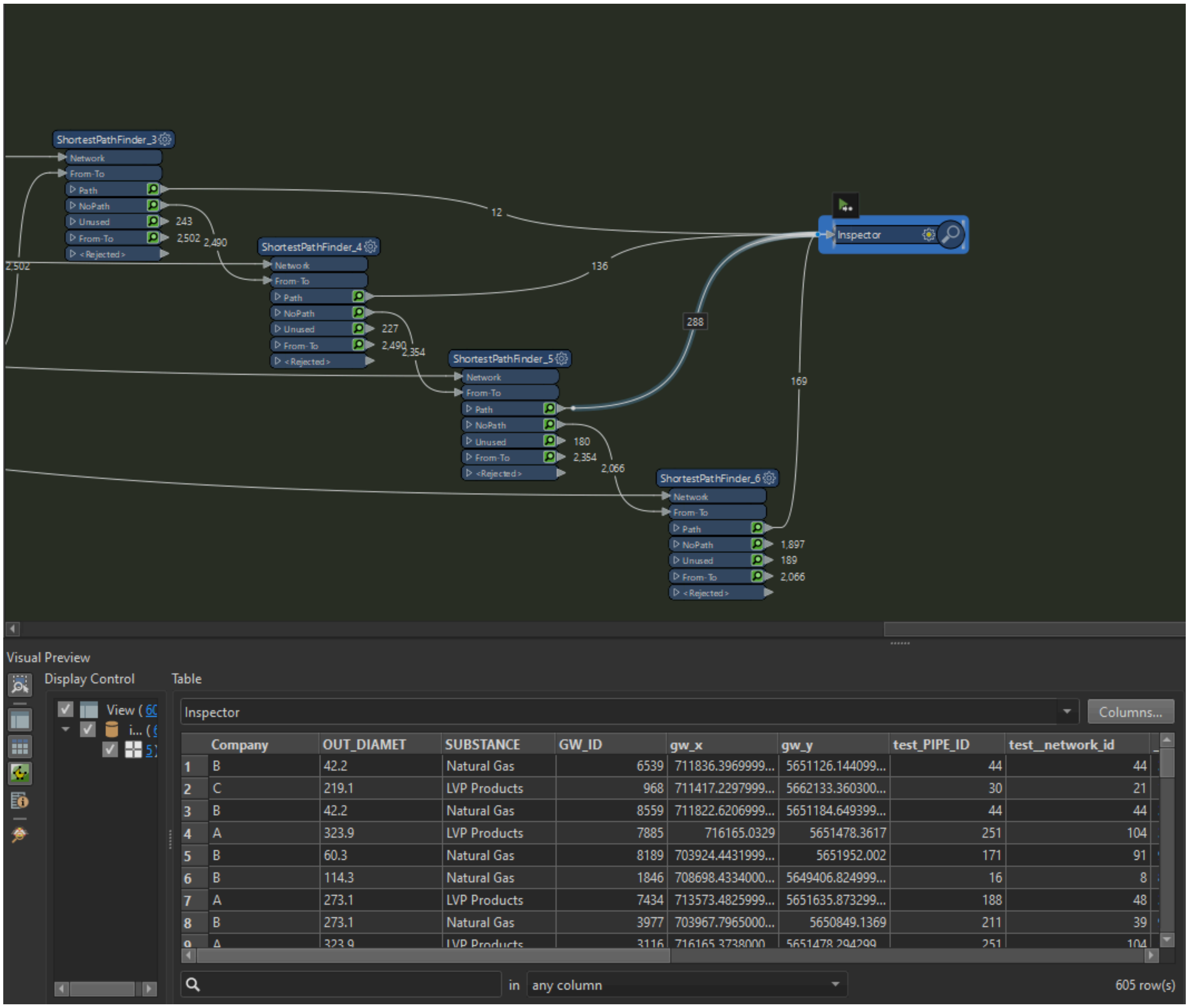


Figure 28: FME Workflow - Cascading Effect

Other geoprocessing tools were attempted in ArcGIS such as line routing and linear referencing, however these methods produced worse results compared to the cascading *ShortestPathFinder* method, therefore the team decided to conclude with the 57% success rate.

Due to this major roadblock, the team was unable to complete the second section of the *Valves* workflow. Finding the nearest upstream and downstream valves was essential in the computation of the volume of lost product since the height that would have been used in the formula would have been the distance between the upstream and downstream valve within the pipeline segment.

Even without the volume of lost product computation, the team was able to successfully analyze the data from the automated workflow and data visualization.

The selected features in Figure 29 shows the most expensive girthweld based on our analysis. There are 3 girthwelds cluttered in the figure with ID's of 1016, 2203, and 6385. All three of these girth welds will cost roughly $68 486 000 if it was to rupture. Table 6 shows the specifics of the girth welds and Figure 30 is the pop shown when the three girth welds are selected.

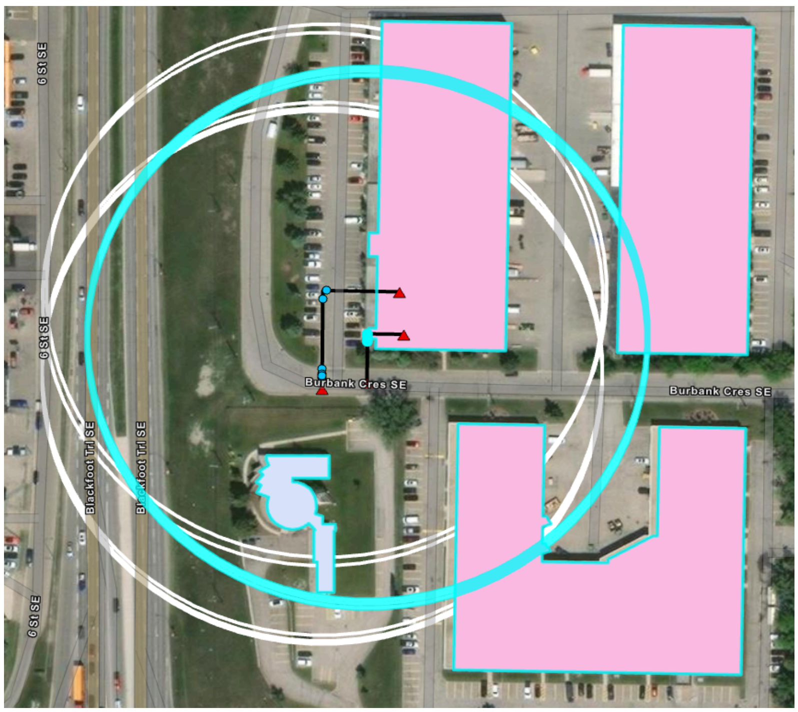


Figure 29: Visualization of the Most Expensive Girthweld

Table 6: Information of the Most Expensive Girth Welds

GW_ID	Total Structure Cost	Total # of People Affected	Total Number Of Structures	Com L	Com S
6385	68486000	341.35	4	3	1
1016	68486000	341.35	4	3	1
2203	68486000	341.35	4	3	1

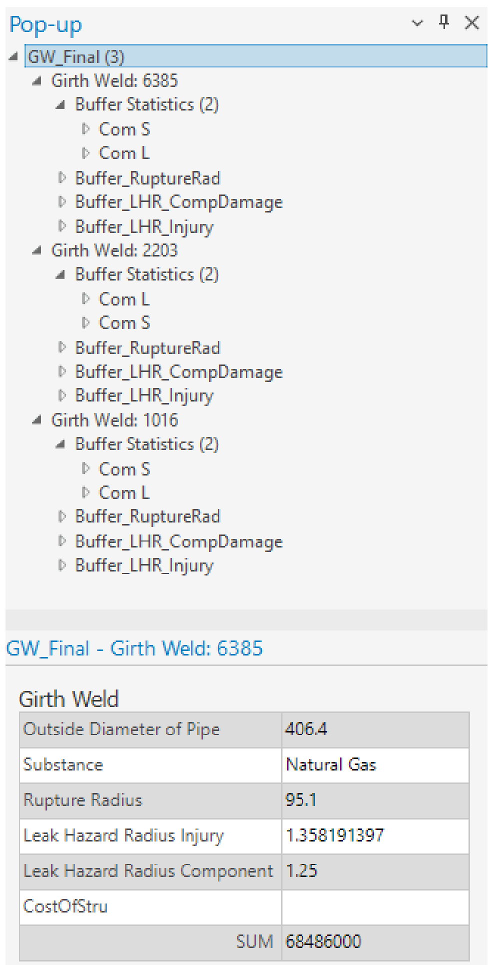


Figure 30: Pop-Up Information of the Most Expensive Girth Welds

In Figure 31, the girthweld selected is 1775 and it is the girthweld that will affect the most people. From Table 7, we can see the 773 people would get affected if this girthweld was to rupture. Figure 32 shows the pop up and has information such as the types of structure and the number of each structure type.

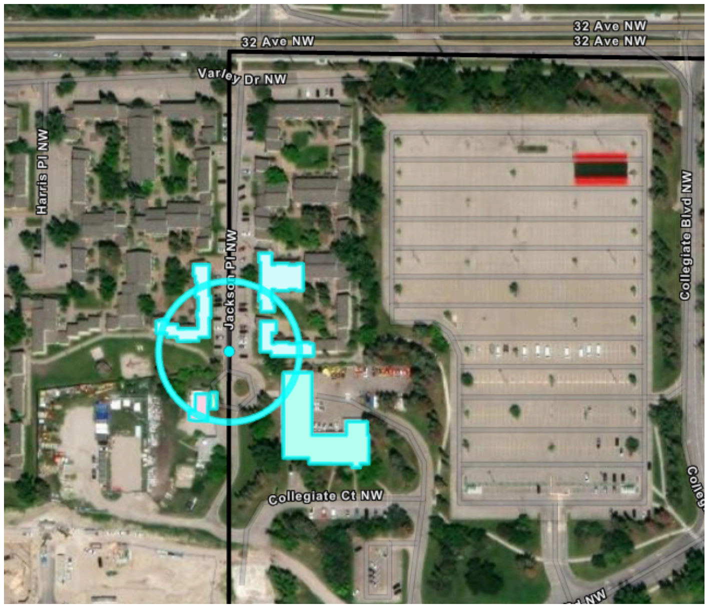


Figure 31: Visualization of the Girthweld Affecting the Most People

Table 7: Information of the Girthweld Affecting the Most People

GW_ID	Total Structure Cost	Total # of People Affected	Total Number Of Structures	University Buildings	House	TownHouse Complex	Detached Garage
1775	46114629	773.17	6	1	1	3	1

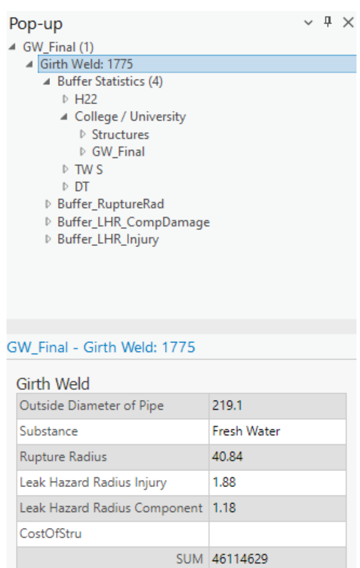


Figure 32: Pop-Up Information of the Girthweld Affecting the Most People

In Figure 32, the team found that the girthweld to damage the most structures was to be girthweld 7354. According to Table 8, there are 85 structures affected costing approximately $12 144 060 in damages. Figure 34 supports the feature selection in Figure 33 by providing the popup with various information about the girthweld.

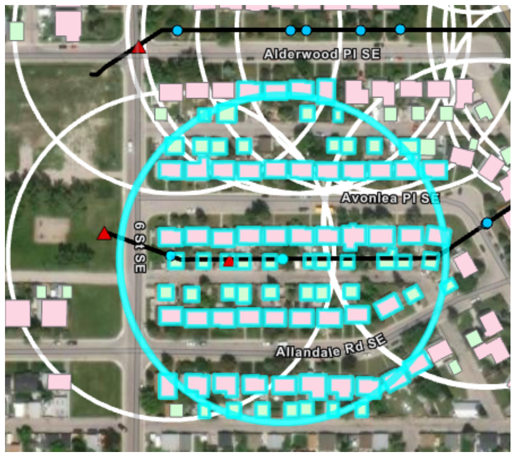


Figure 33: Visualization of the Girthweld Affecting the Most Structures

Table 8: Statistics of the Girthweld Affecting the Most Structures

GW_ID	Total Structure Cost	Total # of People Affected	Total Number Of Structures
7354	12144060	102.6	85

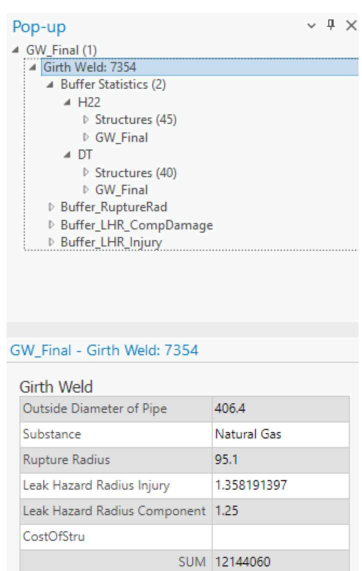


Figure 34: Visualization of the Girthweld Affecting the Most Structures

Conclusion

To reiterate the major aspects, tasks, and products of this project, the end goal was to create a tool that was capable of analyzing the theoretical worst case scenarios of girth weld failures in pipelines, in relation to their rupture radius, on the surrounding area.

The project was successful in completing the data acquisition and classification aspects, which involved collecting and processing data from Open Calgary. However, the main success of the project consists of an automated workflow achieved through the use of FME and the data visualization model completed in ArcGIS. The FME workflow was tested as it was developed to ensure that all calculations and identification of impacted infrastructure was automated.

The closest shutoff valve task faced several struggles surrounding pipeline continuity. Implementation of the ShortestPathFinder transformer improved results, achieving a success rate of just over 57%. Other geoprocessing tools were attempted in ArcGIS such as line routing and linear referencing, but these methods produced worse results compared to the ShortestPathFinder method, which was concluded with the 57% success rate. Completion of the second section of the Valves workflow was halted due to this major roadblock.

Statistics extracted from the FME workflow were analyzed to establish the severity of damage caused by a rupture for each girthweld. The selected features showed that the most costly girth welds, in the event of a rupture, were welds 1016, 2203, and 6385 causing approximately $68,486,000 in damage each. Weld 1775 has the potential to injure the most people in the event of a rupture totalling ~774 people, primarily due to its proximity to a University of Calgary Building. Weld 7354 has the potential to impact the greatest number of buildings totalling 85 buildings with the majority being residential houses.

Despite challenges faced and failures encountered, the project can still be deemed a success as the majority of goals set in the early stages of the project have been met.

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