FINAL REPORT: EMERGENCY PLANNING ESRI ARCGIS DATA ANALYTICS, AUTOMATION, & VISUALIZATION

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Table of Contents

Executive Summary

Emergency planning and management is highly important on a city or municipal level, and the need for a GIS-based framework was made apparent by the City of Vaughan, the project client. A deliverable framework was created for the Situational Awareness Unit (SAU) within the City of Vaughan, and it was called the Situational Awareness Framework Model (SAFM). In their objectives, the client specifically asked for emergency analytics identification, automated models to run those analytics, and a visualization component to display the analysis results.

Appropriate datasets were identified, acquired, and pre-processed in Alteryx Designer. ArcGIS Pro and ArcGIS Online were then used to construct a series of models and operations dashboards that would answer the chosen questions and fulfill the project objectives. When run, the SAFM successfully identified the appropriate GIS analytics set to use, automated those analytics, and visualized the results for the client. Thus, it ended up successfully answering four of the five questions and fulfilling all three project objectives. When a test run for the SAFM was compared to a manual run using Alteryx Designer, most of the results were similar or identical, indicating that the model was accurate. The SAFM was also successful in that Model 2 was run as a part of an emergency exercise on the client's premises. Limitations were provided regarding the nature of the data and the framework itself, and recommendations were provided to the client in the conclusions section. The major benefit of the SAFM is that it is tailored to the client's needs and can easily be altered and extended to answer more questions related to emergency planning and management.

Chapter 1: Introduction

Emergencies can happen anywhere at any time. Most emergencies are unpredictable and can change in scope and impact. Therefore, it is important to plan ahead and be prepared to preserve lives, property, and the environment. For municipalities, this responsibility is typically assigned to an emergency management team. In 2018, the City of Vaughan's Emergency Management Team (EMT) recommended that the City move forward with implementing geographic information system (GIS) emergency mapping in order to "support Emergency Operations Centre and field staff during City-Wide emergencies and exercises" (City of Vaughan, 2017; Czajko et al, 2018). This recommendation was passed onto the Situational Awareness Unit (SAU), a group within the EMT. The SAU are responsible for receiving information from all situational emergencies and properly documenting each situation and/or manually visualizing them on a map for the EMT (Czajko et al, 2018). They play a crucial role in the City of Vaughan's emergency response process. In addition to their recommendations, the EMT prepared a business and technical analysis report, which requires the mapping and emergency datasets from the SAU, reviewed potential software solutions and costs, and identified other jurisdictions with similar systems in place (Czajko et al, 2018). This report also mentioned that the City of Vaughan does not have dedicated staff to this project, emphasizing the need for an outside team to assist in its delivery.

This report outlines a GIS technology and analytics framework solution for the SAU to improve the effectiveness of the emergency response process within the City of Vaughan, hereby referred to as the project client, and fulfill the identified requirements as outlined by the EMT. The framework will aim to aid the client in automating, visualizing, and improving their emergency planning activities. To focus their activities, a list of 105 emergency response questions, relating to City sectors such as business, communication, environment, incident, and more, was provided by the client. To narrow the scope of this project, the list of questions was reduced to thirteen that could be immediately answered with available data. This list was then reduced again to the top five questions based on ranking by importance to the project team, which are outlined in the Objectives section below.

Chapter 2: Objectives

The three objectives of this project, as outlined by the client, are to:

1. Identify and deliver a standard set of analytics/activities/functions for emergency management.
2. Automate GIS analytics in Environmental Systems Research Institute (ESRI) applications.
3. Develop visualization and integration for self-serve analytics in ESRI applications.

These objectives were achieved by creating and delivering a framework that consisted of processed datasets, analytical models, and operations dashboards. To make it easier to refer to these project deliverables, the framework was called the Situational Awareness Framework Model, or SAFM. From here on, it shall be referred to this way using its abbreviated form. The SAFM's components are broken down in the Data, Technology, and Methodology sections of this report.

The SAFM was used to answer the following five project questions from the client's master list:

1. What businesses are affected? Do we have their contact information?
2. How many people are impacted?
3. What are the number of homes affected?
4. What are the high risk areas/hazards we need to protect with first responders and staff responding to emergency?

5. What cross section of the community has been affected? Who has been affected?

Question 5 originally included a third part, “what are their needs?”, and was removed from the Objectives scope. This was because the question is not necessarily situational and may change based on the type of disaster. As a result, the focus for question 5 was placed on the counts of the different cross sections that were affected by the disaster. Cross sections were interpreted as at-risk populations.

Chapter 3: Literature Review

3.1: Introduction to Emergency Management

Emergency planning and management refers to a gathering of individuals from different organizations with the intention of planning their response to emergency situations (Laakso & Palomäki, 2013). Its importance can often be overlooked and underestimated in many cities and municipalities. Access to an automated emergency planning system becomes crucial when both natural and human-caused disasters occur (Laakso & Palomäki, 2013). Appropriate planning, along with good communication, can help in saving many lives and mitigate damages (Laakso & Palomäki, 2013). Now that emergency management can leverage numerous datasets and technologies to improve their response process, it is necessary to define and standardize them. A workshop conducted by the National Institute of Standards and Technology (NIST) brought together emergency responders and used their expertise to understand what information would be most beneficial to the emergency response, specifically for building emergencies (Jones et al, 2005). A set of minimum information requirements were created, including references to using GIS software. An NIST-related study specific to fire department emergency management also concluded that using GIS in their data transfer and visualization activities would serve as an ideal solution (Evans, 2003). It would also serve as the main basis for their emergency systems going forward (Evans, 2003). Therefore, it is clear that emergency management organizations recognize the value of technology, specifically GIS, and are integrating it into their response processes.

Additionally, Canadian municipal governments are required to acquire an emergency management system to know how public authorities and resources will be used and allocated when an emergency occurs (Henstra, 2010). As a result, emergency planning is highly important and expected from municipalities since the level of public interest in emergency management can shift dramatically following a major emergency (Henstra, 2010). This further justifies the City of Vaughan's need for a GIS-based emergency management framework.

3.2 GIS in Municipal Emergency Management

Kevany (2005) has stated that the geographical location of an emergency is often the most crucial piece of information in emergency planning and management. Thankfully, GIS and geospatial analysis have already been successfully incorporated into the emergency management and response process for other jurisdictions in Ontario, including the Regional Municipalities of Durham, York, and Halton, as well as the Cities of Toronto and Brampton (Czajko et al, 2018). It should also be noted that relevant organizations, such as the York Regional Police, also have systems in place (Czajko et al, 2018). Unfortunately, a GIS-based, centralized emergency management system does not exist for all municipalities in Southern Ontario. However, jurisdictions and associated partners, such as law enforcement organizations, do share and provide integration, though the findings are varied. (Czajko et al, 2018). Outside of Ontario, GIS has also been widely applied for the purposes of situational awareness and emergency decision support (Resch et al, 2007; Walawender, 2010).

Spatial decision support system (SDSS) frameworks based on GIS concepts for emergency management have been suggested, created, and implemented for well over a decade (Herold et al, 2005; Tanasescu et al, 2006; Mansourian et al, 2006; Nirupama et al, 2014). These existing frameworks provide some guidance on how the SAFM should be implemented. GIS emergency management recommendations from the literature can also be considered. For example, Resch et al (2007) recommended that the main focus of GIS in emergency management should be on “interactive user design and data integration from different services”. As well, Walawender (2010) suggested that a web-based project framework would be advantageous over a strict desktop one. Fortunately, these recommendations align with those set out by the client. Additionally, other GIS emergency management frameworks have outlined similar deliverables as the ones in this project, primarily relevant datasets, a series of models for automation and analysis, and some sort of visualization interface (Walawender, 2010). These deliverables also align with the objectives set by the client, though a variety of technologies and methodologies are used. Regarding this, the client made it clear through correspondence and suggestions that they preferred that certain technologies and methodologies be used. These two are explained in detail in the Technology and Methodology sections of this report.

In summary, emergency planning and management is highly important, and data and technology play increasingly larger roles in the response process. There is no centralized emergency management system used by all municipalities in Ontario, and therefore a system specific to Vaughan is ideal. GIS is consistently being used more and more in these systems, acting as the main platform in some cases. Contemporary GIS emergency management frameworks in the literature focus on identifying the correct datasets, analytics automation, and results visualization. These objectives align with the client’s project objectives.

Chapter 4: Study Area

As specified by the client, the study area for this project is the Vaughan Census Subdivision. According to the 2016 Canadian Census, Vaughan has a population of 306,233 and 96,657 households within its 273.56 square kilometres (Statistics Canada, 2017). Vaughan is within the York Census Division and, as a result, subsequently a part of the Greater Toronto Area (GTA). Within the City some of the notable landmarks are the Vaughan Metropolitan Centre subway station on the Yonge-University Line, as well as acting as a cultural hub; Vaughan Mills, an outlet mall and attraction for tourists and locals alike; and Canada's Wonderland, the only amusement park in the GTA (City of Vaughan, 2019). A map of Vaughan can be found in Appendix A of this report, as Figure 2.

Chapter 5: Data

The data used to answer four of the five project questions and create the SAFM were extracted from three primary sources: Simply Analytics provided by Environics Analytics, Statistics Canada, and York Region Data Portal. The four questions were segmented into two categories based on the nature of the datasets: demographics and businesses.

5.1: Demographics

Demographics play an important role in determining who and what type of people are affected by an emergency situation. By better understanding the affected population and household type by geographic area, EMT can effectively react and respond to specific emergencies.

In an emergency event, it is important for the response team to consider the affected population. A population database helps allows for a better assessment of the emergency, communication, and response to evacuate or relocate individuals from their homes or businesses. The Statistics Canada based on Census population database will provide relatively accurate population data by dissemination area (DA) in the City of Vaughan. It should be noted that the spatial distribution of population dramatically differs between night and day as people commute from their homes to work.

The concept of daytime population refers to the number of people present in an area during normal business hours. This differs from evening hours, which is what nighttime population is for. As different age groups require different needs, it is crucial that the response team is able to identify populations from different age groups during both times. Environics Analytics offers the daytime population data set required as a shapefile at the DA level of geography. Environics is a privatized company which does not offer public information on their daytime population methodology. However, on their website it is briefly stated that the data uses comprehensive estimates of populations at home and at work in all geographic areas, as opposed to nighttime population provided by the Census data (Environics Analytics Group Ltd., 2019). A sample of daytime and nighttime population maps were generated using SimplyAnalytics to show major differences between daytime and nighttime populations in, found in Figures 3 and 4 of Appendix A. The total day and nighttime populations are shown in Table 1 shown below:

Table 1: Daytime and Nighttime Populations in Vaughan, ON, Toronto, ON, and Canada (SimplyAnalytics & Environics Analytics, 2019)

	Vaughan, ON (CSD)	Toronto, ON (CSD)	Canada
Total Daytime Population, 2019	372,893	3,098,154	36,750,837
Total (Nighttime) Population, 2019	330,195	2,988,140	37,465,430

A study estimated day and nighttime population distributions in U.S. cities for emergency response activities, and downtown daytime populations were found to be 6.9 to 28.6 times greater than nighttime population in the same census tracts (McPherson & Brown, 2004). These population differences could greatly impact the emergency planning process, and subsequently affect any final decisions (Public Safety Canada, 2013). In another study on population density modelling for disaster risk assessment, fine data are especially needed when performing local scale analysis for disaster modelling to adequately estimate vulnerable populations and, in some cases, casualties. Time-specific population data can aid in these predictions at any time (Tenerelli et al, 2018). Thus, it can be concluded that both day and nighttime population are relevant datasets to include in the SAFM.

Besides the number of people being affected, it is crucial for the client to know how many homes are being affected in the area as well. Shelter is an essential necessity for a person's wellbeing. When a family's home is affected by disasters, such as floods, power outages, or hazardous conditions, it is crucial to efficiently evacuate and relocate them to some sort of temporary shelter. Therefore, it is important to know how many homes, houses, and apartments are affected. In Statistics Canada based on the Canadian Census from 2016, houses are split into several categories: single detached, semi detached, row houses, other attached and other single-attached dwelling. Apartments are split into: apartments in a building that has five or more storeys, and apartment or flat in a duplex and apartment in a building that has fewer than five storeys. Both of these are provided at the DA level.

There are also major differences in the approach of emergency disasters towards at-risk groups (Fussell, Sastry, & VanLandingham, 2010). At-risk population groups are recognized as potentially vulnerable age groups. In this project, that definition was extended to young age groups (0-14) and seniors (65 and over) as they are less prepared for emergencies, and thus could potentially be more at risk than other population groups

(Hoffman, 2008). These age groups are provided through Statistics Canada within the 2016 Census at the DA level. Individuals in these age groups require additional needs before, during and after an incident, including but not limited to: maintaining independence, communication, transportation, supervision and medical care (Hoffman, 2008). Some examples include misunderstanding written or verbal communications for emergency instructions or being unable to reach points of distribution for medical assistance due to mobility impairment (Hoffman, 2008). As a result, it is important to identify vulnerable age groups and include them as datasets in this project, as they require special attention to better assist their needs in an emergency situation.

In this project, questions 2, 3, and 5 fall under the Demographics category.

5.2: Businesses

Emergencies can happen at any time, even during work hours. To better assist the client in reaching the affected groups of people in need besides population at home, it is important to understand where the businesses are affected, how many people resides in individual businesses, and how to contact them. The business directory data were obtained through the York Region Data Portal, which consist of information such as business name, location, type, employee range, website, and phone number. By incorporating this dataset into the SAFM, the client can identify appropriate ways to effectively respond to businesses affected by specific emergencies. In this project, question 1 falls under the Business category.

5.3: Hazards/Risks

In this project, question 4 falls under the Hazards/Risks category. Unfortunately, appropriate data were not obtained, and as a result a model was not constructed. Therefore, question 4 was left unanswered within this project. This decision is further addressed in the Limitations section of this report.

5.4: Other Data

Additional layers were downloaded from York Region Data Portal and Scholars GeoPortal (Ontario Council of University Libraries, 2019) to support the dashboard template for SAFM, which will be further explained in the Methodology section of this report. The spatial data that were used as additional layers were police service facilities, hospital locations, healthcare centres, hazard points, and solid waste sites. These layers help support EMS to identify the closest emergency and first response services to assist in responding to emergency situations.

A data table, complete with all sources and additional information, is provided in Table 4 under Appendix B of this report. Is summarizes all of the datasets in this section.

Chapter 6: Technology

Data pre-processing was conducted in Alteryx Designer (Alteryx Designer, 2018). Alteryx is an analytical workflow software for streamlining data processing with repeatable processes created in a graphic user interface. Alteryx is capable in processing and creating spatial data using many standard analytical spatial processes. Additionally, non-spatial data can be manipulated using joins, calculations, and other processes similar to SQL. These capabilities make Alteryx a good choice for handling processing data for this project. The workflows are found in Appendix C of this report as Figures 5 and 6. (Alteryx Designer, 2018).

The SAFM's analytics, automation, and visualization components were built in ESRI ArcGIS Pro and ArcGIS Online using the ModelBuilder feature. The client indicated a preference for these platforms in email correspondences (G. Czajko, personal communication, October 18, 2019). ArcGIS Pro is an adequate platform for GIS analysis provided by ESRI (Barsai, 2018). Additionally, a jurisdictional review of other Ontario municipalities and their emergency management systems was performed by the City of Vaughan's Emergency Management Program Committee (Czajko et al, 2018). The review found that ArcGIS Pro or ArcGIS Online were implemented in the Regional Municipality of Durham and the City of Brampton. That, along with a comparison matrix of potential solutions created by the Committee, justified the use of ArcGIS Pro and Online for this project (Czajko et al, 2018). Both platforms were licensed and accessed through Ryerson University.

Chapter 7: Methodology

A suggested methodology for the SAFM to follow was provided by the client (G. Czajko, personal communication, October 15, 2019). The methodology was modified to fit the scope of the project, and these modifications are explained further in this report. The methodology was turned into a simple flowchart, as seen below in Figure 1:

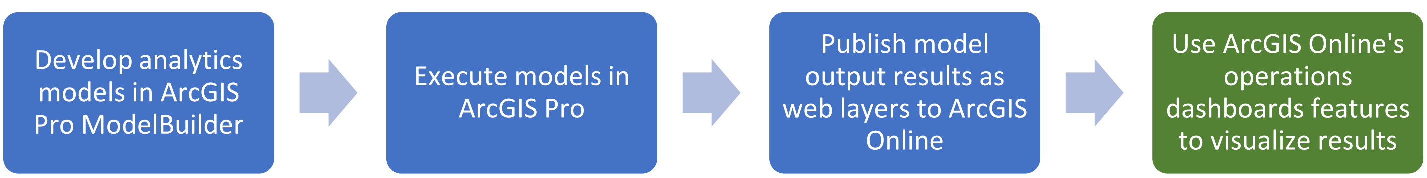

Figure 1: Methodology Flowchart for SAFM in ArcGIS Pro and ArcGIS Online

7.1: ModelBuilder Models in ArcGIS Pro

Pre-processed datasets outlined in the Data section of this report were added to ArcGIS Pro. ModelBuilder was then used to construct analytics models that would process the data and display output layers, ultimately answering four of the project's five questions. Two models were constructed based on the categories that the questions were segmented into: businesses and demographics. Both models output spatial features with fields that are relevant to the questions they answer. Model 1 includes the descriptive information for each business, if available, including name, address, NAICS code, and phone number. Model 2 had custom fields that contain the minimum, maximum, and estimated proportional values for the population, population by age, households, dwellings by type, daytime population, daytime population at work, daytime population at home, and daytime population at home by age. Minimum values were calculated by aggregating the demographic fields across all DAs that are within the incident area. Maximum values were calculated by aggregating the demographic fields across all DAs that intersect the incident area. Proportional values were calculated by taking a ratio of a DA's area that intersects the incident area and the total DA area, multiplying the ratio by the demographic variables, and aggregating all ratio values for each DA that had been intersected.

Table 2 explains which model answers which questions:

Table 2: ModelBuilder Models and Their Corresponding Answered Questions

Model Name	**Questions Answered**
Model_1_Vaughan_Businesses	Question 1: What businesses are affected? Do we have their contact information?
Model_2_Vaughan_Demographics	Question 2: How many people are impacted? Question 3: What are the number of homes affected? Question 5: What cross section of the community has been affected? Who has been affected?

ModelBuilder model workflows are found in Appendix C of this report, as Figures 7 and 8.

The models were executed in ArcGIS Pro, and their output layers were manually published to ArcGIS Online as web layers. Publishing to ArcGIS Online was crucial as this would allow the client to share these services with other stakeholders. Multiple individuals would then be able to access and use the published services.

ArcGIS Server was originally included in the methodology recommended by the client, specifically for geoprocessing services publishing and to integrate ArcGIS Pro and ArcGIS Online. However, due to time constraints and the platform's steep learning curve, the client ultimately suggested against using ArcGIS Server. Therefore, platform access was not obtained and the original methodology was modified to omit ArcGIS Server. As a result, the models were not published as geoprocessing services to ArcGIS Online as was originally intended because ArcGIS Pro did not allow this (Environmental Systems Research Institute, 2019). Therefore, manual publishing was employed instead.

7.2: Publishing to ArcGIS Online & Dashboards

In ArcGIS Online, the published web layers were added to web maps, and three separate operations dashboards were created from the web maps to visualize the results of each model. The dashboards displayed necessary information from each output layer to answer four project questions. The operations dashboard for Model 1 displays the emergency incident area, the total number of businesses in the area, a section where business information is displayed, including a phone number for contact, supplementary layers of information, such as police stations, and a legend. The operations dashboard for Model 2 displays the incident area, the total daytime population, nighttime population, number of households, number of houses, number of apartments, a larger section displaying all of the demographic data for the incident area, supplementary layers of information, and a legend. Examples of these dashboards are found in Appendix D of this report, as Figures 10 and 11.

Chapter 8: Results & Discussion

8.1: Immediate Results & Emergency Exercise

The SAFM successfully provided an immediate visualization of results in the ArcGIS Online operations dashboards from the analysis conducted in ArcGIS Pro using the ModelBuilder models. The results fulfilled the project's three objectives and answered four of the project's five questions.

The client invited the project team to attend an emergency exercise on their premises. Two of the team members attended and brought a preliminary version of the SAGM, specifically Model 2, to test run using an input polygon provided at the exercise. The model ran successfully in ArcGIS Pro and produced relevant results. The results were published to an ArcGIS Online operations dashboard and then visualized on a screen. This exercise confirmed that the model had successfully completed all three project objectives and effectively answered question 2.

8.2: SAFM Results Verification

To verify that the SAFM was producing accurate results, a manual test model was created in Alteryx Designer to simulate the use of the tool during an actual emergency. This model was specifically created to simulate the SAFM's Model 2, the one that calculated demographic data. A workflow of this model can be found in Appendix C of this report, as Figure 9. The test emergency was based on a power outage event that affected the City of Vaughan on May 7, 2017 (Zarzour, 2017). The referenced article specified an incident area between Bathurst Street on the east, Dufferin Street on the west, King Sideroad on the north and Hwy. 7 on the south. Following these boundaries, an incident area polygon was drawn and added as an input into both the manual test model and SAFM Model 2. Both models were run and their results were compared in Table 3 below:

Table 3: Comparison Table of Manual (Alteryx) and Actual (ArcGIS Pro) Results for Power Outage Test Scenario

Order	Variable	Alteryx Results	ArcGIS Pro Results
1	Total Population	18,101 - 54,774 (34,687)	11,335 - 54,774 (est. 34,686)
2	Total Population 0-14	5,015 - 13,930 (9,269)	3,025 - 13,930 (est. 9,268)
3	Total Population 15-64	11,680 - 36,300 (22,757)	7,445 - 36,300 (est. 22,756)
4	Total Population 65+	1,390 - 4,525 (2,644)	860 - 4,525 (est. 2,644)
5	Total Households	5,260 - 16,344 (10,086)	3,243 - 16,344 (est. 10,086)
6	Total Houses	6,235 - 18,805 (11,990)	4,005 - 18,805 (est. 11,989)
7	Total Apartments	295 - 705 (306)	105 - 705 (est. 305)
8	Daytime Population	15,132 - 124,917 (28,090)	9,273 - 124,917 (est. 28,088)
9	Daytime Population at Work	4,764 - 94,618 (8,862)	2,933 - 94,618 (est. 8,861)
10	Daytime Population at Home	10,368 - 30,299 (19,228)	6,339 - 30,299 (est. 19,227)
11	Daytime Population at Home 0-14	5,171 - 14,225 (9,443)	3,017 - 14,225 (est. 9,443)
12	Daytime Population at Home 15-64	3,971 - 11,991 (7,388)	2,503 - 11,991 (est. 7,387)
13	Daytime Population at Home 65+	1,226 - 4,083 (2,397)	819 - 4,083 (est. 2,396)

Upon comparison, it was apparent that the results were similar between the two models. The minimum range values differed greatly but this was evidently due to different algorithms identifying different DAs to be within the incident area as well as the incident area very closely following DA boundaries. The maximum range values were identical between the two models and the proportional values were very close, with the largest difference being 2 units. The reason for this was likely a difference in decimal accuracy due to units, the calculations in Alteryx were done in square kilometres while the ArcGIS Pro model uses the default spatial units in ArcGIS Pro. Example dashboards of the test scenario can be found in Appendix D, as Figures 10 and 11.

Chapter 9: Limitations

9.1: Data Limitations

The SAFM provides a conceptual framework for the client to build, enhance and interact with customized pre-set datasets. The module allows for ample flexibility as this is primarily a framework model and the limitations, although minimal, can be addressed with the appropriate enhancements and datasets. Based on the conceptual framework, one of the fundamental limitations is the datasets used to build the framework. Several datasets such as census variables, daytime population metrics and the business directory have methodologic limitations. The reliability and methodology of the datasets is dependent on the source and time frame of the datasets available. Census variables such as population, dwelling counts and population by age cohort, are only available on a census year basis. As such, this dataset can only be updated every five years and the reliability of the datasets is susceptible to government policy, given the 2011 Census was cancelled, causing a ten-year gap between datasets. As such, the datasets used in the framework could fluctuate in 2021 and 2026, which could force the clients to purchase datasets from third party vendors.

The second dataset with significant limitations is the Business Directory, which is sourced from York Region through their data portal. Although this is a robust dataset, the limitation is behind the methodology for the data collection and extraction. The business directory requires significant investment, given the data is collected by frequenting the sites and manually tracking the business in the market. As this is a key dataset used to identify businesses in the market, the accuracy of the dataset can only be as good as the level of detail the data collectors can provide.

The final major dataset used is the Environics Analytics Daytime Population data which is a private dataset with information on the daytime population in a market. Given questions 2, the SAFM is intended to provide the client with information on the population during the day, but because this is a private dataset there are several limitations in the methodology. Daytime Population is calculated by analyzing the nighttime population, business, schools, care/retirement homes, and more, to build assumptions around the population in a market during the day. However, as the dataset is private, no significant methodologic paper is published and the assumptions behind the methodology are fairly limited. Given the dataset is simply an estimate of the population, the granular geography used in the framework results in significant issues with the dataset. Beyond the limitation of the datasets, there are still issues with how the data is extracted given this is a manual process. This limitation can be overcome as the client works in the framework and can potentially finalize the datasets they require and automate that extraction process.

The final limitation with the data aggregated and used for the analysis is the availability, which causes significant accessibility issues. There was limited access to specific data portals, such as the York Region Open Data Portal, as the amount of publicly available data is fairly limited. This directly interrupts the SAFM's capacity to address one of the objective questions (question 4) as data accessibility for hazard datasets (water pipes, containment factories, and energy plants).

9.2: SAFM Model Limitations

There are some key limitations with the SAFM, given the methodology used to extract the analytics the clients required. One of its capabilities is to allow users to insert custom geographies and the model extracts the data, however when analyzing data at a DA level, the area proportional methodology is used. This calculates the level of coverage the custom geography covers particular DAs and then uses the percentage of coverage to export the demographics data. For example, if a geography covers 25% of a DA, then the model assumes demographics, such as population, are evenly dispersed and extracts 25% of the population. This results in an ecological fallacy as there is an overarching assumption that the demographics (population) are evenly dispersed across the DA. An ecological fallacy is an assumption in statistical analysis which occurs when pre-emptive assumptions about a group of individuals being identical depend on where they reside is made. In this instance, the model directly assumes an area proportional methodology and creates a fallacy. Although the methodology strives for accuracy, the overarching assumption forces significant limitations. In retail geography, this methodology is widely used to determine demographics of trading areas and is conservative in the assumption. In emergency planning and situational awareness, this creates limitations given the assumptions. In this project, it is significantly better to overestimate the population impacted rather than underestimate, however there is still no methodology which allows the client to retrieve data with 100% accuracy.

9.3: The Modifiable Areal Unit Problem

Overall, combining the data and SAFM limitations leads to the underlying Modifiable Areal Unit Problem, which is prominent in geographic analysis. This is a limitation in when data is aggregated but presents different results leveraging the same analysis that is applied to the same data. This is driven through two primary scale and zone implications as the scale impact. The scale impact is when different results are exhibited, leveraging the same analysis with the same datasets, however the scale of the aggregating is vastly different. For example, when a user draws emergency incident areas, they need to be aware of the spatial extent their geographies cover, and if larger proportional DAs are used this could create a scale issue. However, there is validity behind the scale effect because although the results are identical, the spatial scale vastly varies. The second impact is the zone effect, which assumes the analysis, data and scale are identical but the units used for aggregation are fundamentally different. For example, if the client attempts to draw incident areas in hexagon cells or grids using a 2 KM buffer, the results will differ given the dimension of the polygons where the datasets are stored.

Ultimately, the limitations behind the SAFM will expand as more comprehensive and dynamic datasets are used, but the framework, at least, provides a foundation for the clients. This allows ample flexibility, creates capacity, and allows the client to enhance the tool as drastically as needed.

Chapter 10: Conclusions & Recommendations

The SAFM is a significant framework model designed and automated with an end user lens to help derive appropriate analytics and insights, improve automation through GIS processing, and develop visualizations of the results for emergency response purposes. Based on the research questions presented by the client, the framework directly answers several questions. This was pre-determined by the client and only specific questions had been selected to address driven by their importance, validity and data recommendations. To address the research questions, several data sets from multiple sources were selected for the processing and visualization components. A suggested methodology was modified for the project, and it was decided that Alteryx Designer, ArcGIS Pro, and ArcGIS Online would be used to create the deliverables. The SAFM successfully automated analytics, produced results, and visualized them for the client. Further success was expressed at the client's emergency exercise. Verification of the SAFM's results using Model 2 showed accuracy for most demographic data, though alternate verification methods are recommended.

The functionality of the SAFM is significant as it improves current emergency response processes while allowing users to be flexible with design and implementation. There are several methodology and implementation limitations which impact the build out and enhancement of this framework. Data methodologies, data sourcing, framework methodology, MAUP and ecological fallacies directly impact the functionality of the framework. However, the limitations can be overcome as the client becomes more capable with the end product. This leaves significant room for enhancements and improvements through better data accessibility. Some datasets, such as the daytime population metrics, would be very powerful to the client once appropriately licensed. However, the SAFM has significant user flexibility, and the recommendation is more geared towards fully implementing the model with the team and enhance using new datasets. Overall, the final recommendation is for the client to continue enhancing the framework and building out other models to answer other emergency questions.

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Appendix A – Report Maps

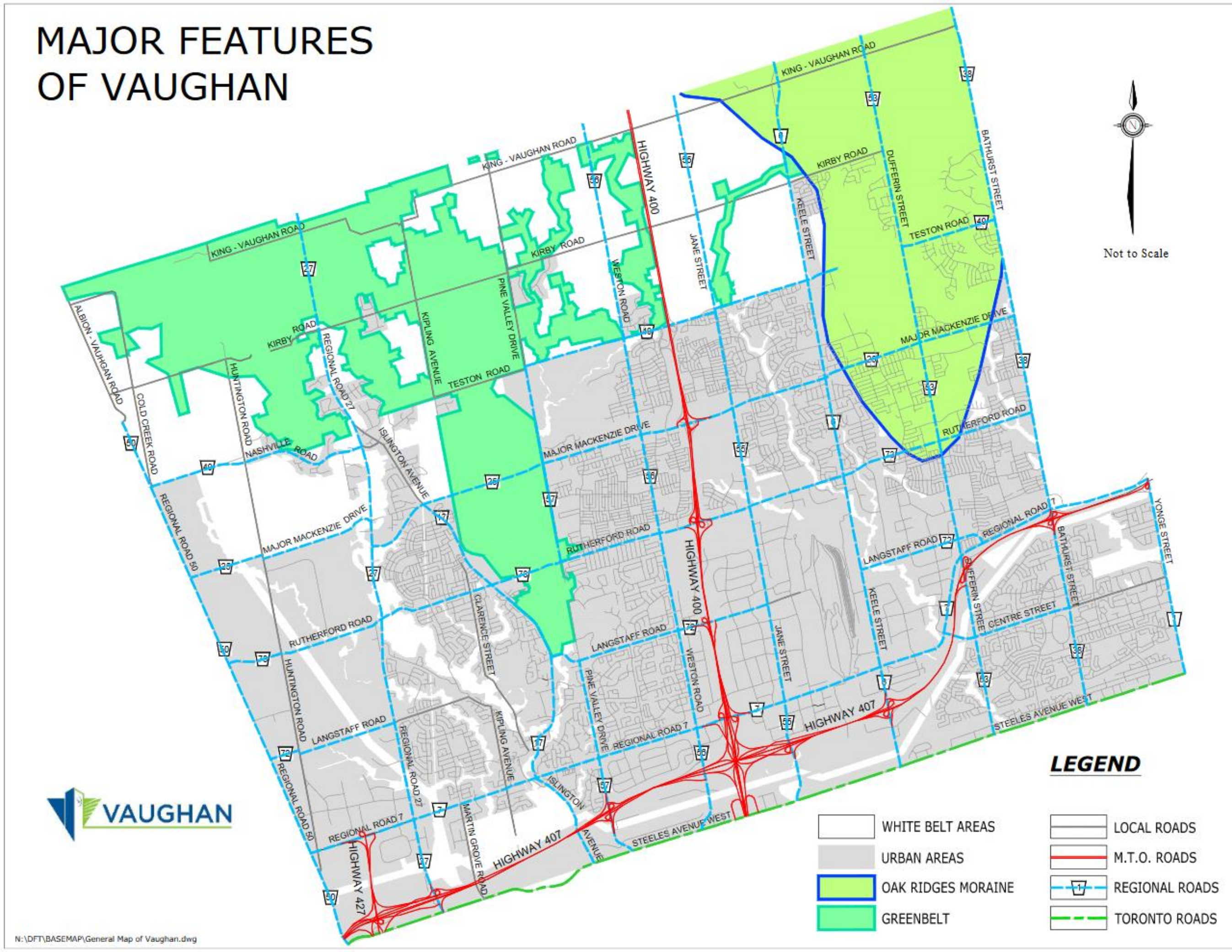

Figure 2: City of Vaughan Study Area Map (City of Vaughan, 2019)

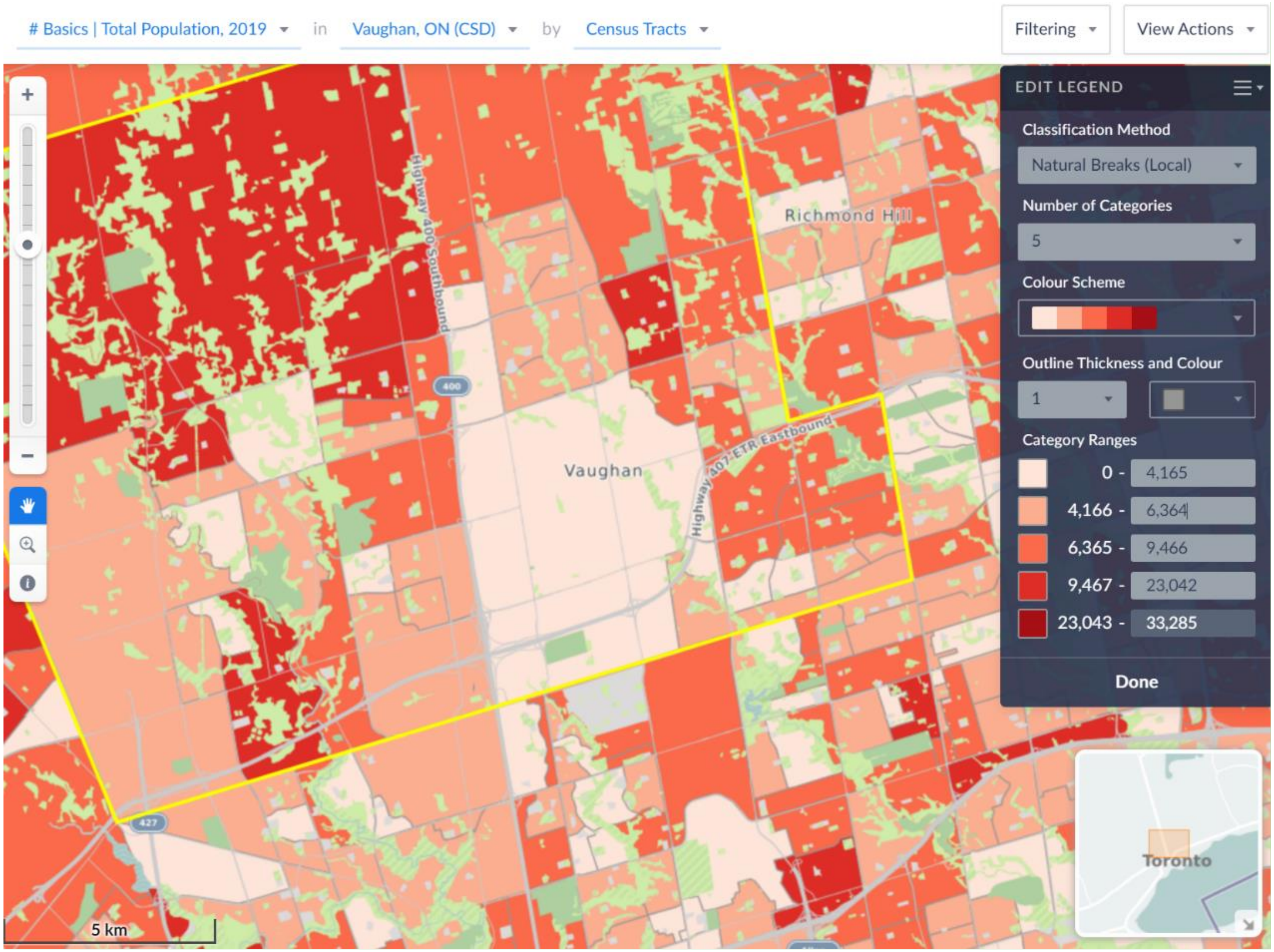

Figure 3: (Nighttime) Population in Vaughan, ON CSD Using Census Tracts. Thematic Map classification method using natural breaks. Source: SimplyAnalytics & Environics Analytics, 2019.

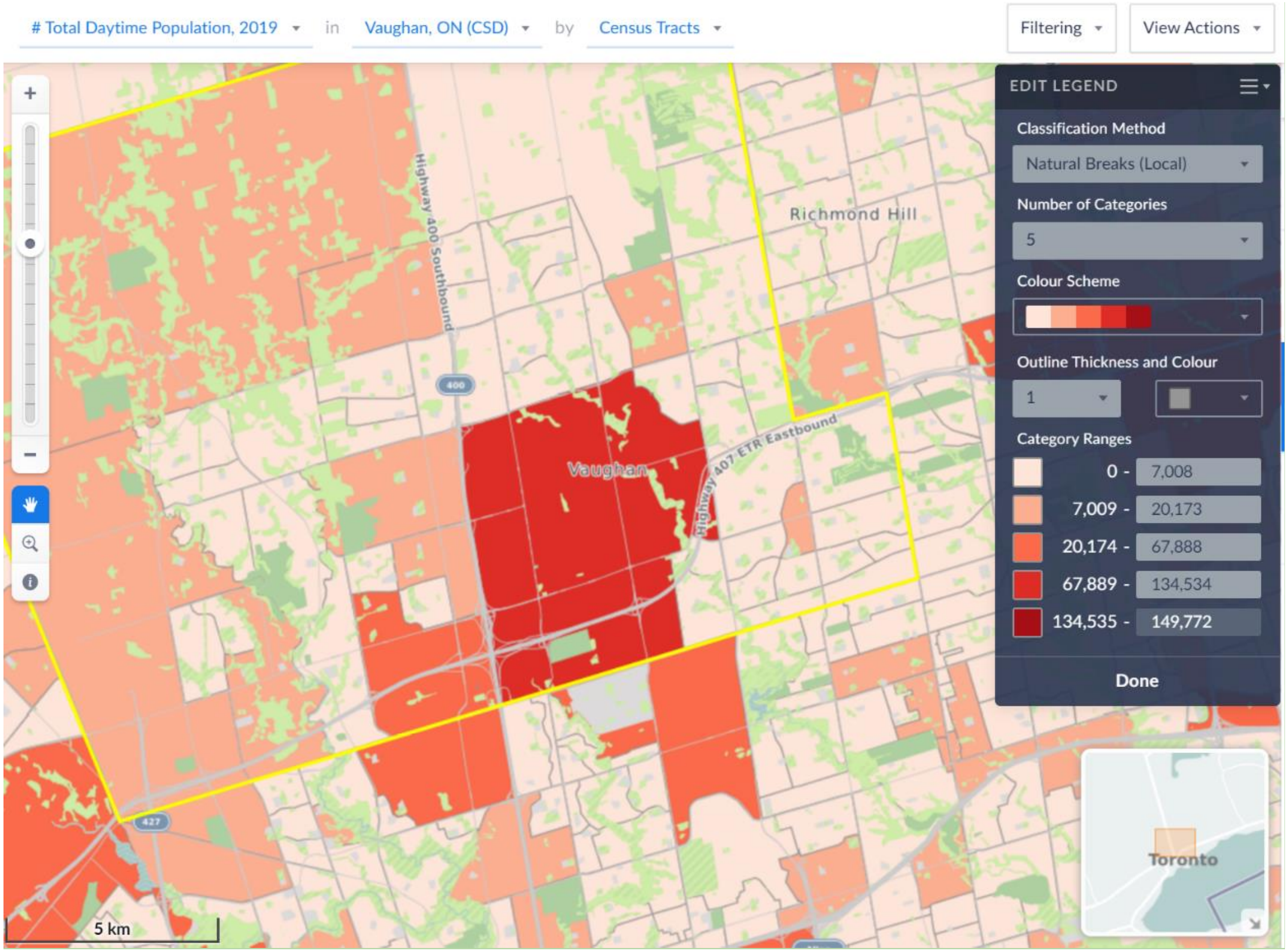

Figure 4: Daytime Population in Vaughan, ON CSD Using Census Tracts. Thematic Map classification method using natural breaks.

Source: SimplyAnalytics & Environics Analytics, 2019.

Appendix B – Project Data Table

Table 4: Project Data Table & Data Sources

Name	Description	Format	Year	Source
Daytime Population	Sourced from Environics Analytics, this data set will provide the estimated Day Time Population by specific age cohorts.	Dissemination Area, Shape File	2016	Environics Analytics
Nighttime Population	Sourced from Census Canada, the dataset will provide an accurate count of population by age cohort.	Dissemination Area, Shape File	2016	Statistics Canada
Business Directory	A comprehensive dataset of all business (local, national, international) banners and brands collected by York Region and contains the exact location of all businesses their addresses, contact information, NAICS breakdown and employee counts.	Point Location, Database	2018	York Region
Dwelling Counts	Counts of different dwelling types; Houses and Apartment.	Dissemination Area, Shape File	2016	Statistics Canada
Toronto Police Services Facilities	Geographic distribution of all Police District stations, offices and Court Services offices in the City.	Point Location, Shape File	2019	Toronto Police Services Data Portal 2019
Health Care Facilities	Location of hospitals, long-term care facilities, outpatient clinics, nursing stations, and community health centres. All locations are classified using the North America Standard Industry Classification System (NAICS) and Standard Industry Classification (SIC), for further analysis.	Point Location, Shape File	2018	Scholars GeoPortal

Hospital	Hospital locations in Ontario, as governed by the Public Hospitals Act. Hospitals are institutions for health care providing patient treatment by specialized staff and equipment. Each hospital corporation may have more than one site (location).	Point Location, Shape File	2018	York Region Data Portal 2018
Solid Waste Site	This dataset contains point locations for operating solid waste locations in York Region as well as the name of the facility address and hours of operation. These facilities store, process, or dispose of hazardous waste. The Environmental Services Department verified attribute information. Generalized locations are also contained in the attributes of this data for web mapping purposes.	Point Location, Shape File	2018	York Region Data Portal 2018
Fire Stations	Locations of Fire Stations across Canada. All locations are classified using the North America Standard Industry Classification System (NAICS) and Standard Industry Classification (SIC), for further analysis.	Point Location, Shape File	2018	Scholars GeoPortal
Hazard Points	Points that are navigational hazards for marine travel. This includes, but is not limited to, abandoned bridge piers or cribs, rocks, and shipwrecks.	Point Location, Shape File	2018	Scholars GeoPortal

Appendix C - Alteryx Designer Workflows & ArcGIS Pro ModelBuilder Models

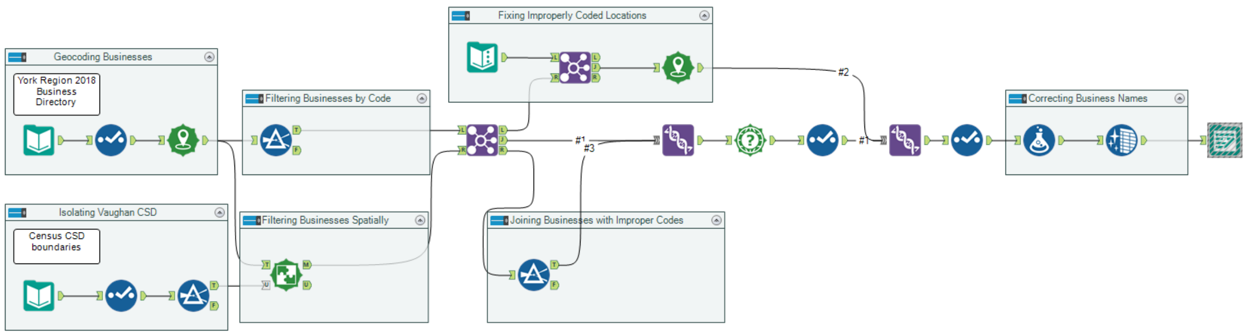

Figure 5: Alteryx Workflow 1 - Pre-Processing Vaughan Business Data

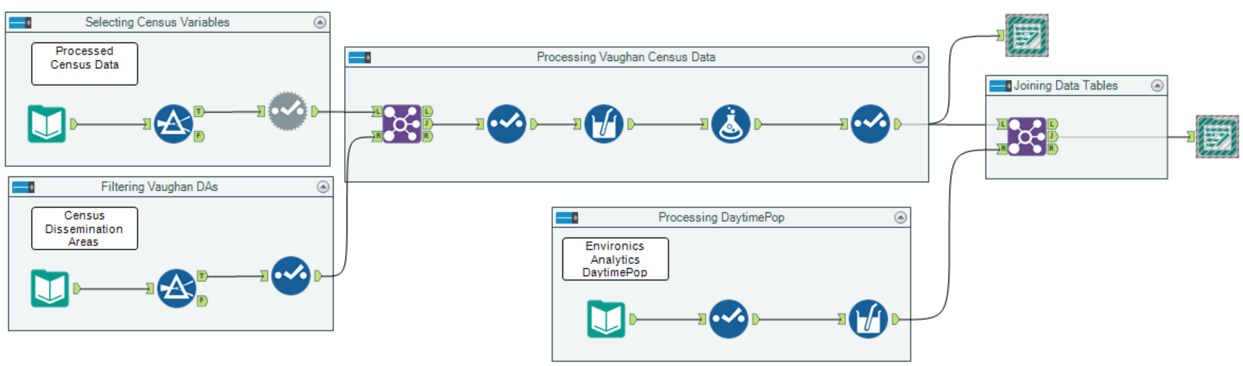

Figure 6: Alteryx Workflow 2 - Pre-Processing Vaughan Demographic Data

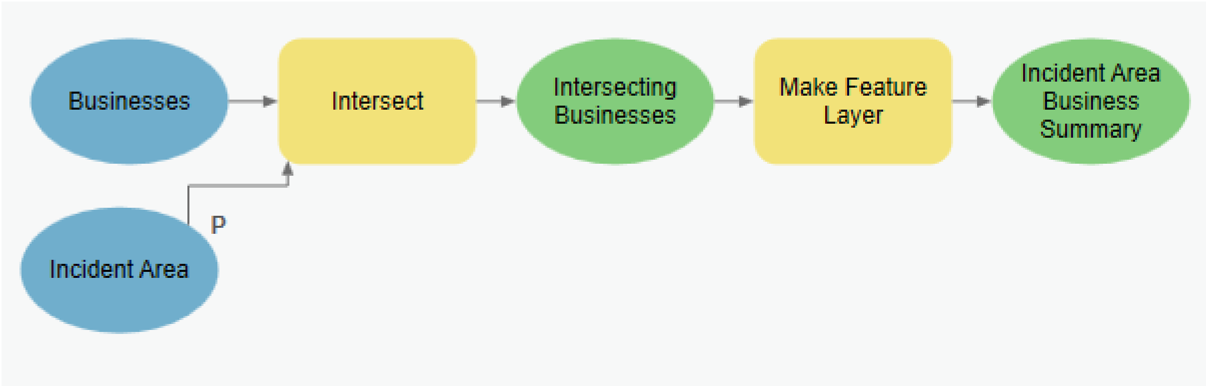

Figure 7: ArcGIS Pro ModelBuilder Model 1 - Vaughan Businesses

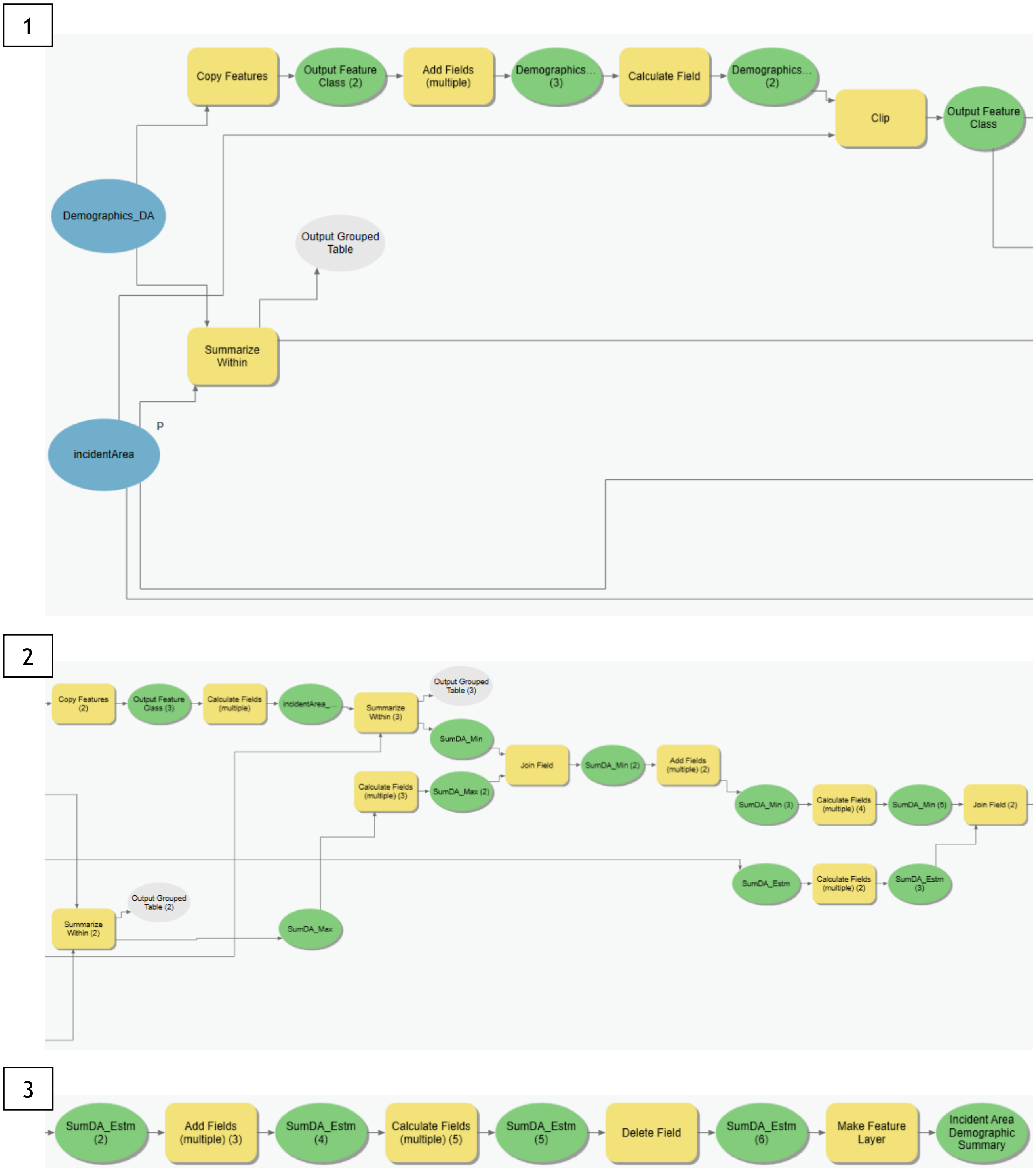

Figure 8: ArcGIS Pro ModelBuilder Model 2 - Vaughan Demographics

Note: Due to the large size of Figure 8, it was split into three separate images and labelled based on order.

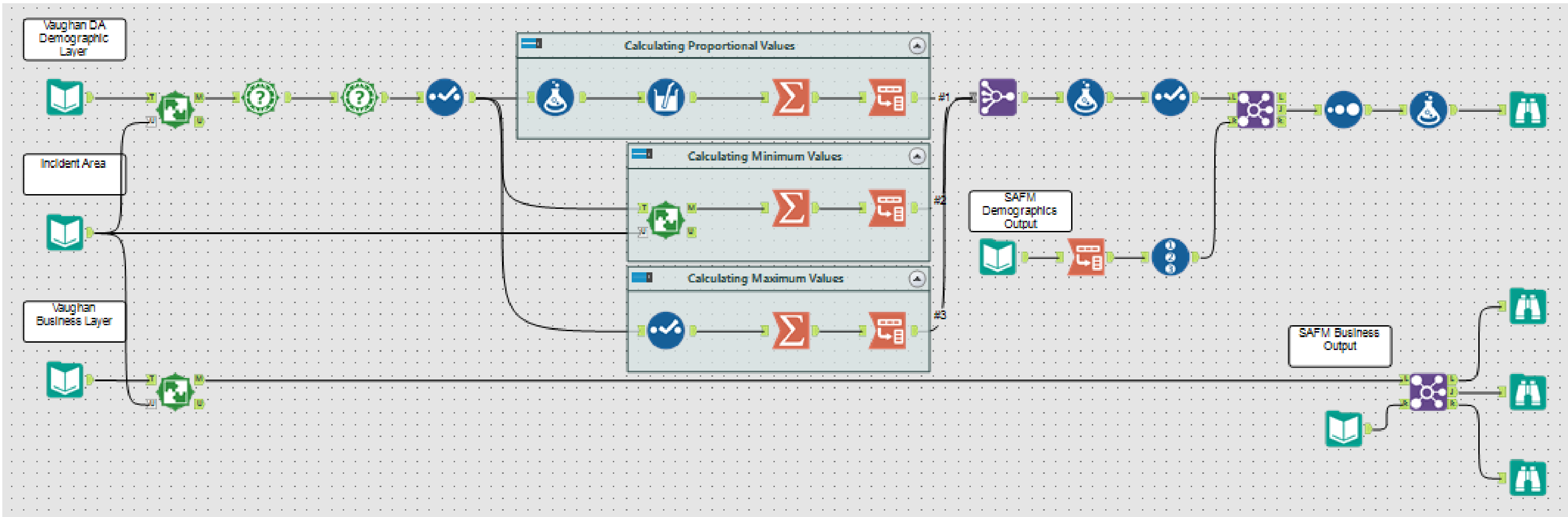

Figure 9: Alteryx Designer Comparison Workflow for Test Scenario

Appendix D – ArcGIS Online Operations Dashboards

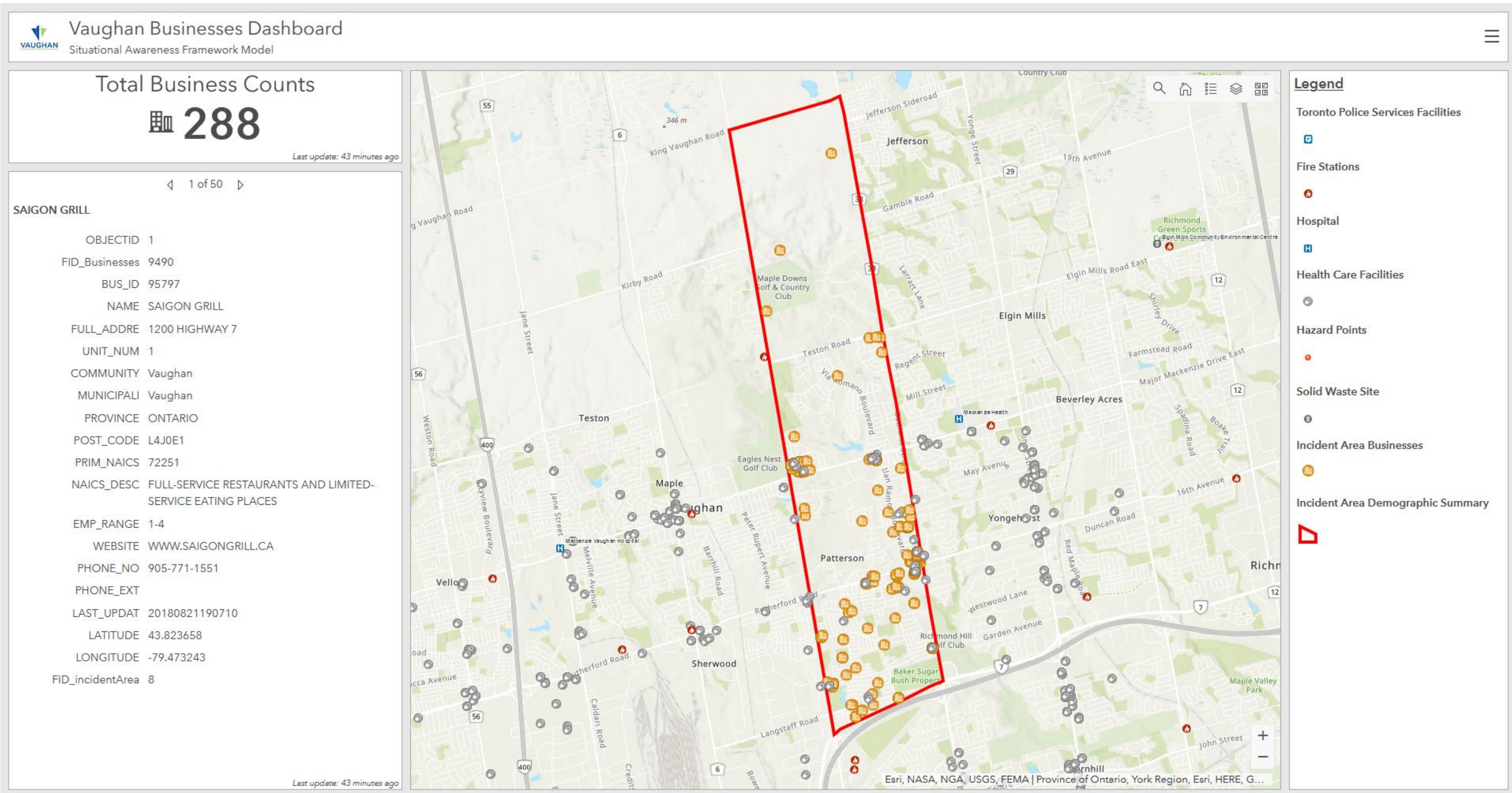

Figure 10: Operations Dashboard for Model 1: Vaughan Businesses

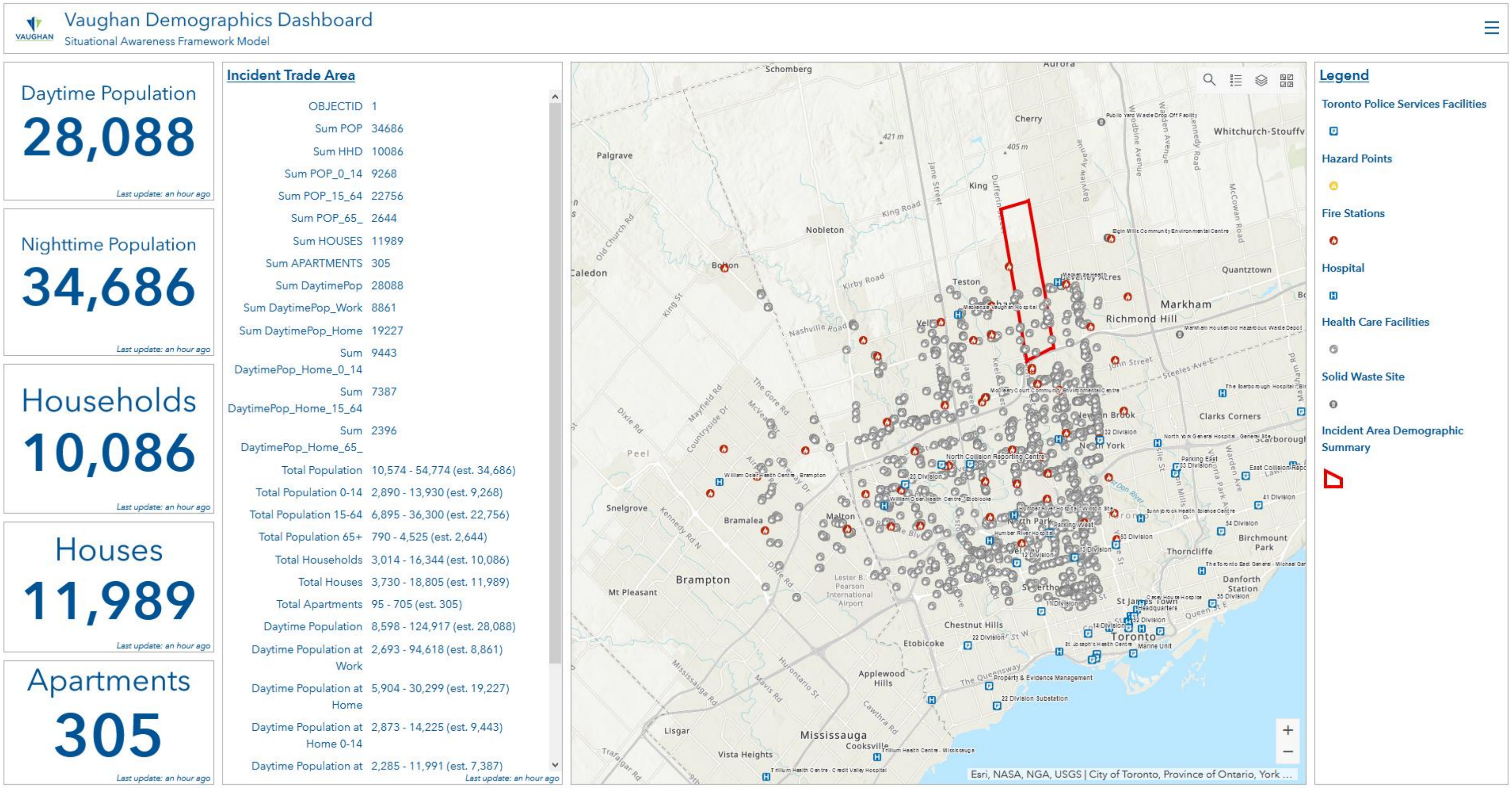

Figure 11: Operations Dashboard for Model 2: Vaughan Demographics