Safe Walk:
A Network Analyst Framework for Safe Routes to School

by

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To my mother, Penelope Alfonso

Table of Contents

List of Figures

List of Tables

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List of Abbreviations

CVESD	Chula Vista Elementary School District
GIS	Geographic information system
PCS	Projected coordinate system
SANDAG	San Diego Association of Governments
SANGIS	San Diego Regional GIS Data Warehouse
SES	Social and Economic Status
SRTS	Safe Routes to School
TIMS	Transportation Incident Mapping System
USC	University of Southern California
VGI	Volunteered Geographic Information

Abstract

Geographic Information Systems (GIS) can greatly strengthen Safe Routes to School (SRTS) programs by helping stakeholders to visualize service areas and study the process of walking to school. Information from a GIS can help drive policies and change processes at a district level. The purpose of this study is to provide a framework for how GIS, particularly Esri’s Network Analyst, may be used by a school district in SRTS programs. This study demonstrates how to analyze and visualize the process of students safely walking to school for two elementary schools in Chula Vista, California. This framework provides districts with procedures on how to acquire GIS data, preprocess data for Network Analyst, and analyze data by setting up a network with appropriate barriers and impedances. It shows district administrators a simple yet effective means of using a GIS to strengthen SRTS programs. This study resulted in maps of several routes within the Harborside Elementary and Wolf Canyon Elementary school zones. The maps and outputs helped to determine where the model worked well and where there were areas for improvement. Overall, Esri’s Network Analyst extension was found to be an effective tool in modeling the safest routes to school; however, each school zone needed model customization. This research also emphasizes factors that school districts would need to consider in the use of GIS for SRTS programs. Such implementations of GIS may help school districts better understand the process of students walking to school and help district administrators to make better-informed decisions regarding SRTS programs.

Chapter 1 Introduction

Small changes in lifestyle can be made to improve health outcomes; one small change that has lasting impact is walking. Walking to school has many benefits for children. These benefits include less childhood obesity, air pollution, and traffic congestion. Therefore, many public agencies are concerned with walking to school.

Nevertheless, what seems a simple goal is complicated by safety concerns for students. To alleviate this problem, Congress created the Safe Routes to School National Partnership (SRTS) in 2005 (Huang and Hawley 2009). The SRTS National Partnership provides funding to local communities to improve walking outcomes among youth. The school districts and communities administer programs and projects to improve walking outcomes. The Safe Routes to School programs (local programs) are sustained efforts by schools, parents, community leaders and governments to increase the health and well-being of children by enabling and encouraging them to walk and bicycle to school. SRTS programs study conditions around schools and conduct projects and activities that work to increase safety and accessibility, and reduce traffic and air pollution in the school vicinity. SRTS programs rely heavily on Geographic Information System(s) (GIS) data to drive decisions; many projects are concerned with the collection and use of GIS data. Using GIS data can be effective in running a SRTS program (Safe Routes to School National Partnership 2016). GIS provides school districts with the necessary tools to administer SRTS programs.

GIS can help school districts visualize areas surrounding schools and provide more information about the process of walking to school. As will be discussed further in Chapter 2, GIS can help school districts become more knowledgeable of their service area, prioritize workload to locations with the greatest needs, and manage time-intensive tasks. One prominent example is the Flagstaff Unified School District which has built a web GIS framework for the ongoing collection of SRTS data (Huang and Hawley 2009). These tools can easily be used by school districts to streamline the process of finding walkable school routes as well as influencing school policies and safety measures for increasing school walkability.

GIS technology has vastly developed and is more accessible for users in an extensive array of fields outside of geography such as public planning, real estate, social services, forestry, archaeology and many more. K-12 educators and staff may also use GIS to improve school programs. Tools such as Modelbuilder, Python, and the Network Analyst extension make GIS more accessible for school districts. District users can take advantage of using these tools with relative ease.

A large part of GIS is building tools to make the work of a user easier and streamline a process. A school district would want to identify the safest route to school that a student should take. One powerful tool in achieving this is the ArcGIS's Network Analyst extension. This tool is helpful in modeling routes with the least amount of impedance or defined "cost" for traveling down a path. GIS can make the process of identifying the safest route to school easily managed for a large quantity of students.

1.1 Motivation

There were several motivations for building a framework for a school district to utilize a GIS to manage a Safe Routes to School program. These motivations included helping districts to assess walkability around neighborhoods, using tools to service to a large number of students, and help increase the use of GIS in a K-12 setting.

GIS tools will help to improve walkability within a school district. Walkability is a measure of how friendly an area is to walking and improving walkability improves health outcomes. The ability to walk to school has benefits for students and parents. Walkable school routes help to decrease obesity, air pollution, and traffic (Jones and Sliwa 2016). These outcomes contribute to not only better health outcomes but a more positive learning environment. Parents and students alike would have a more positive commuting experience. There have been efforts to collect local walking and biking data in various regions (Safe Routes to School National Partnership). Data can be used and applied to a GIS to increase “walkability” throughout a community. Rattan et al. (2012) created a model to easily automate the analysis of walkability in Ontario, Canada. The model measures walkability for a general population in a region; however, this model can be adapted to fit an elementary-age population. GIS tools like these can be used in building other tools. The tool that Rattan et al. built help to study the entire service area as opposed to the individual safest route; however, information about the area can be applied to Network Analyst algorithms to find the safest route.

This work will contribute to the study of automation and development framework in GIS. Safe Routes to School programs often happen at a larger scale impacting the whole community. Effectively streamlining the process of finding walkable school routes should not only save time but also give school districts a greater understanding of their local population. This research allows for school district administrators to effectively drive policy and more efficiently run programs designed to help students walk to school more safely through the understanding of the overall process. Many school district staff do not have a background in using a GIS to better understand the process of walking to school and many school districts do not have funding for an in-house GIS specialist. Having models, tools, and a framework helps to simplify the process of getting meaningful information from open, publicly accessible data. Safe Routes to School programs often rely on parent and student volunteers for walking surveys, which makes things difficult for some districts as they have varying demographics. Some populations of people have more resources than others and can devote more time to the program than others. By using open data, the school district can save on time and resources expended on collecting Safe Routes to School data.

Not every issue can be solved using the same models and processes. Some may work for one issue but may not work for another. This research will attempt to create a standardized model and framework that can be adapted to the 45 schools in the Chula Vista Elementary School District. This model will help simplify the process of finding walkable school routes so that a district user can take a more hands-on approach to applying GIS to the Safe Routes to School program. This study will help school districts import data into the GIS and process the data into meaningful information. It builds the capacity of school districts to use GIS as a tool to serve their student population.

1.2 Questions

Building a framework to help districts with the Safe Routes to School program comes with its own set of questions and considerations. These questions are generally sectioned into questions of design, effectiveness, and replicability.

We often build tools for specialized purposes in a GIS to help with specific issues. Usually, these tools are built by the combination of multiple tools. This study uses several GIS tools for a specific purpose, mainly identifying a single safe route to school for each student. This study addresses how we can customize tools to meet that purpose but can still adapt these tools to other purposes.

Designing the framework also requires a process of measuring the overall effectiveness and evaluating the tool. It needs to be determined whether the tool achieves the desired outcome and where can the tool be improved.

The intention of building this framework is to replicate it so that it can enhance the Safe Routes to School program in the Chula Vista Elementary School District. Therefore, the question of replicability comes up. If a tool becomes too highly specialized, there may be problems with using the tool in multiple schools. As will be discussed later, the study area may represent a large school district with a huge amount of variance within its boundaries. This project explores the scope and limitations of automation and replication.

Overall, this thesis explores whether the Esri's Network Analyst extension is a viable tool for use in the Safe Routes to School program. This thesis explores how effective is the tool in finding safest routes, how school districts can acquire and manage data, and how to evaluate the outcomes to improve the tool.

1.3 Study Area

This study models the Harborside Elementary and Wolf Canyon school zone areas in the Chula Vista Elementary School District (CVESD). CVESD is a school district in California, headquartered in Chula Vista, in the South Bay area of San Diego County. The 103-square-mile (270 km^2) district is the largest elementary school district in the State of California. It spans the area between the City of San Diego and the United States-Mexico border. It has 45 schools and 29,300 students. Of them, 45% receive free or reduced lunch and 35% are English-language learners. 318,148 people live in the school district boundaries (US Census Bureau 2016). Considering race and ethnicity, 68% are Hispanic, 13% are White, 11% are Filipino, 4% are African American, 3% are Asian or Pacific Islander, and 1% are other.

Chula Vista has strong socioeconomic divides east and west of the I-805 freeway. The Mello-Roos (community and road tax) has systematically pushed lower income families to the west side where living expenses are cheaper (Luzzaro 2012). The east side has a lot of newer construction and a relatively higher number income families than the west side. On the west side, there is a high percentage of low income Latinos. Harborside is located on the west side. Wolf Canyon is located on the east side (Figure 1).

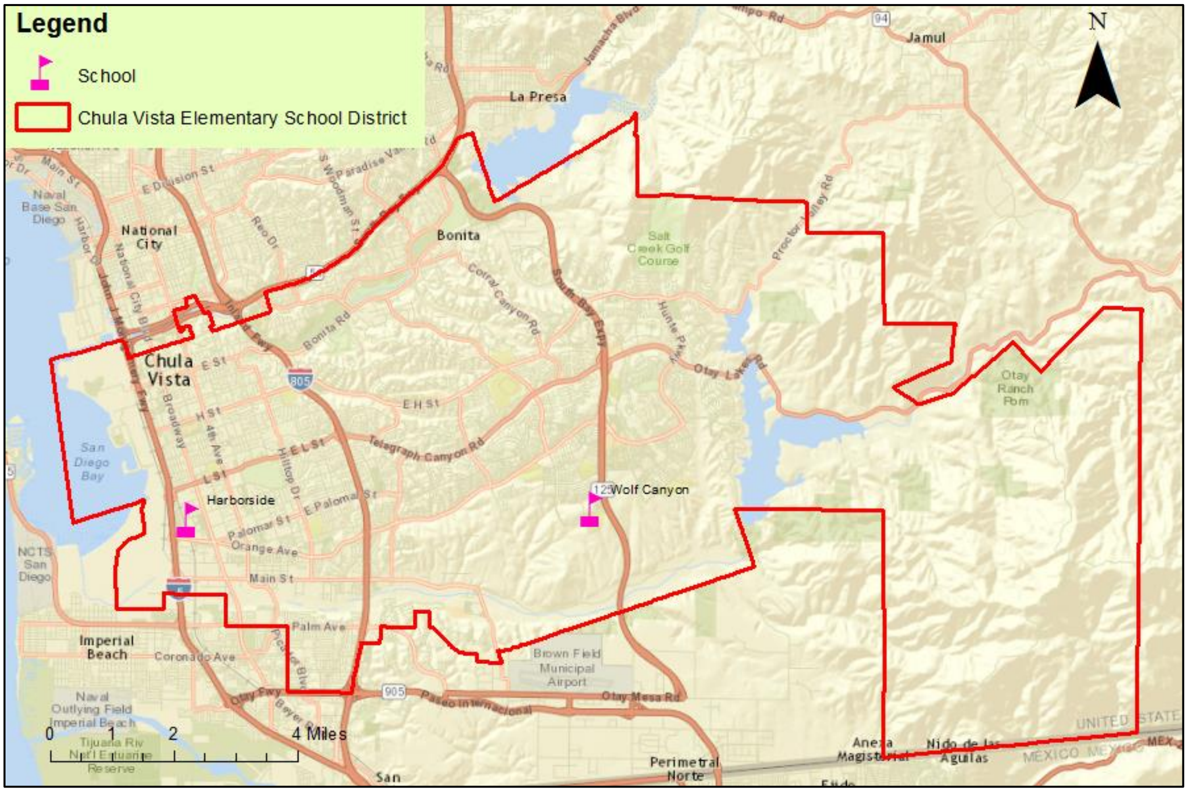

Figure 1 Map of Chula Vista Elementary School District

1.3.1. *Harborside Elementary*

The Harborside Elementary school zone is blended in with heavily commercial and traffic congested areas. Harborside Elementary contends with older roads and more crime in the area. The school is surrounded by businesses in an area that would generally be considered crowded and is above the state average in terms of students receiving free meals (poverty indicator) (Ed-Data 2017). Harborside Elementary would be a great area for a district administrator to focus on identifying safe routes to school due to the needs of its students and area diversity.

1.3.2. *Wolf Canyon Elementary*

The Wolf Canyon Elementary school zone is in a mixed suburban and rural area. Wolf Canyon was built in an area with new infrastructure and less congested roads. Wolf Canyon's families are generally higher income; fewer students are receiving free meals than the state average (Ed-Data 2017). Overall, the school district has a lot of variance among schools. Designing a tool would need to address the range of needs throughout the school district.

1.4 Thesis Outline

Following the general concepts in the introduction, there is a review of the related work and literature, definition of a methodology for using Network Analyst to find the safest routes to school, results of the analyses, and final discussion of the findings.

In Chapter 2, related literature is reviewed. To understand the relevance of this study, more information is given on the Safe Routes to School program, its benefits, and complications that deter students from walking. Additionally, backgrounds on GIS modeling and automation are further established.

In Chapter 3, methods are further discussed. The framework focuses on how a school district can acquire the necessary data to import into ArcGIS. Once imported, data is prepared for use in the Network Analyst tool. The tool defines barriers and impedances and solves for the safest route to school. The methods chapter describes the outputs from the model.

Chapter 4 reviews the results of the tool. Each analysis provides its own set of outputs. It evaluates the success of the model and discusses the outcomes through various tests. The results help to identify the success of the model in one study area versus the other. The results also help to determine where the model is most effective and where the model can be improved.

Chapter 5 provides conclusions based on the results and overall process. Chapter 5 will provide key takeaway points from each chapter as well as recommendations for future study. The Conclusion chapter explores limitations within the model and suggests improvements to counteract the limitations in possible future work.

Detailing the process helps to provide insight to future scholars and those administering the Safe Routes to School program. Reviewing components of this thesis can help others in enhancing their programs.

Chapter 2 Related Work

Building a GIS framework for a Safe Routes to School program requires knowledge in several distinct areas. To understand the overall purpose of the process and the application, a school administrator must understand the benefits of walking, as well as how and why students are often deterred from walking. The Safe Routes to School programs are often grant funded, so it is beneficial to understand the goals of SRTS evaluations. Backgrounds in GIS modeling and automation are required to provide a foundation to implement the technology. Specifically, those who design SRTS programs and GIS technologies must learn about the process of modeling a cost-weighted route in Network Analyst to emulate the process of walking to school.

2.1 Safe Routes to School

Safe Routes to School programs are sustained efforts by schools, parents, community leaders, and governments to help improve health and well-being of children by supporting and encouraging them to walk and bike to school. SRTS programs look at conditions around schools and conduct projects and activities that work to improve safety and walkability and to reduce traffic and air pollution in the school vicinity (Safe Routes to School National Partnership 2015). To better understand the need for the Safe Routes to School program and the goals of creating a GIS model to support the program, a district will need to know the benefits of walking, the problems that arise with walking to school, and the goals of Safe Routes to School evaluations.

2.1.1. *Benefits of Walking*

For the past decade, urban and transportation planners have been trying to imbed physical activity in the daily commute to school. Much research has been done on the benefits of walking to school. It can be synthesized from several studies to culminate in various claims about the benefits of walking. Studies have found that active transportation, or the act of students walking or biking to school, is not directly linked to decreasing childhood obesity. Saunders et al. (2013) claim, however, that it does have positive effects on preventing diabetes. Nevertheless, the study only looks at a single variable contributing to obesity and not a holistic health view. Green et al. (2013) found in a systematic review that walking contributed to a lower mortality rate among individuals even though it did not have a significant impact on cardiovascular health. In a meta-analysis of walking groups involving 1,843 participants, Hanson and Jones (2015) found that walking reduced mean difference of systolic blood pressure and diastolic blood pressure and depression.

2.1.2. *Problems with Walking to School*

Walking to school may have many benefits, but it also comes with its own set of complications. Complications generally include safety concerns centered on traffic, crime, and the physical characteristics of the roads such as the speed limit, road type, and direction of travel.

Scholars have examined the factors that contribute to students not actively commuting to school. Ermagun and Samimi (2015) claim safety is addressed as a major concern in school trips. Using a three-level nested logit model to explain the motives behind school trips, they find that improving safety could increase walking outcomes by as much as 60%. Other criteria such as cost of driving, travel distance, vehicle ownership, and commute time also contributed to active transportation, but according to their model only under 2.37% of the time. Safety is the primary concern for parents in allowing for their children to walk to school, making programs such as Safe Routes to School essential. GIS programs and automation can help to strengthen these programs. SRTS programs should thoughtfully consider safety in a GIS framework since safety is the primary concern of the population that they are serving. Increasing safety should be planned in the design of any model.

Physical environment influences safety; therefore, a district user should examine the attributes of the study area. There seems to be much variation on the specific means of increasing safety. Well et al. (2016) claim the general themes are centered on calming traffic, increasing pedestrian walking infrastructure, and reducing crime. Waygood and Susilo (2015) find that “good local shops” increase the perception of safety and make for more walkable school routes, while traffic speed does not have an effect. It is important to note that this study took place in Scotland which may not be applicable in a U.S. cultural context. A population in Scotland may value certain land attributes and features more than a population in the United States. For instance, in America, the presence of liquor stores could correlate to more crime in an area, or at least give the perception of crime. In fact, in another article with a different secondary author, Waygood suggests that reducing traffic speed is positively associated with walking to school.

Although there are many complications with modeling an abstract idea such as “safety,” having a framework can help school districts by presenting a clearer picture of the principles involved. For example, Jones et al. (2016) suggest that students will more often avoid the shortest route to school in favor of a route with less perceived crime and graffiti. Furthermore, GIS is not a rigid scientific process; in fact, people’s on-the-ground “knowledge” often leads to abstractions of the ground “truth.” These abstractions will often manifest during such processes as the cartography or data schema creation. A model for finding safe school routes should increase school commute safety. Such a model should include traffic, crime, and urban form, as most of these topics were mentioned as factors affecting safety and school commutes.

A district may use other examples of active community to find significant factors for an SRTS GIS framework. Many evaluations examine the environmental effects of walking. In the last 50 years, the United States has seen a shift from small, neighborhood schools to larger schools in densely populated areas. McCann and DeLille (2000) claim that from 1977 to 1995, the rate of walking or biking to school by American children decreased significantly by 37%. Studies have shown that urban form helps predict travel mode to and from school (Schlossberg et al. 2006). Commutes to school can be improved simply by placing sidewalks, crosswalks, and covered bike parking (McDonald et al. 2013). Davison et al. (2006) have shown that the participation of children in physical activity is positively correlated with publicly provided, accessible infrastructure and transportation infrastructure such as sidewalks, controlled intersections, and access to points of interest and public transport. Dunton et al. (2009) find that there are more than fifteen other studies that make claims that urban form, or physical environment, contributes to obesity. The physical environment affects how students get to school; nevertheless, district officials are often not integral in the design of streets around schools. Some schools may be older with outdated architectural design and placement. Therefore, the SRTS program may only have the means to study the area around the school. When they are unable to transform the walking environment, they must make data-driven decisions on routes. School officials must work within the constraints of the environment and use data to the greatest possible effect.

2.1.3. *Safe Routes to School Evaluations*

Walking or bicycling to school helps to increase a child’s daily, physical activity; however, major physical environment changes such as the creation of permanent infrastructure are often needed to improve the safety and convenience of walking routes. Because of this, the

Safe Routes to School National Partnership offers competitive funds that encourage school walking and biking programs for students to commute in spite of the various obstacles and impedances. These funds often require evaluation efforts.

Most evaluations look at percentage of increase and decrease of active commuters in student surveys. Boarnet et al. (2005) found that children who participated in SRTS programs were more likely to walk or bike to school, as much as 15% versus 4% of the time. Staunton et al.'s (2003) evaluation has shown that the program was effective in increasing walking (64%), biking (114%), and carpooling (91%) at participating schools in Marin County, while decreasing use of private vehicles (39%). These evaluations are important for a district, because sustaining a program with funds is helpful to a program. External funding accounts for the majority of school program funds. It is important to note that most of these evaluations focus on the end goal of increasing walking outcomes rather than the overall health of the student population. If most funders are interested in the number of walkers rather than improving the overall walkability of the area, then increasing number of walkers should be a goal of the GIS framework. The network analyst extension would be effective in finding safe routes within the constraints of less than ideal infrastructure and other barriers and impedances to walking.

2.2 Modeling Safe Routes to School

There are a few articles related to GIS modeling of safe school routes that can help guide the development of a model for the Chula Vista Elementary School District's Safe Routes to School program. An important distinction in such articles is between models and measures that apply to neighborhood areas and those that apply to specific routes within neighborhoods.

One GIS application that measures neighborhood walkability is called Walk Score. Walk Score is a free and publicly available website for public health researchers and practitioners to examine neighborhood walkability. Results from the Duncan et al. (2011) study suggest that Walk Score is a valid measure of estimating some facets of neighborhood walkability. However, Walk Score data is commonly used for those in the realm of real estate, urban planning, government, public health, and finance. There has been no evidence to suggest that this application is effective in serving schools or a school-age population.

Another model must be used to simply and effectively serve school districts and a younger population who will have different needs than an adult population. SRTS programs need a model at a different scale and study different variables looking at the neighborhood surrounding the school district rather than the city scale. A district can examine certain components of Walk Score, because safety is a part of walkability. Building a framework for SRTS may include some key components of Walk Score, but emphasize variables that contribute to the overall safety. The districts further improve client service by building a tool specific to the user. Having a tool that finds the safest route from the student’s home to school encourages more participation from the family as a route establishes a more concrete set of directions for the student. The student will have a specific route to travel down rather than solely relying on information about the whole service area.

GIS modeling may also be used to find characteristics of a particular area. Zhu and Lee (2008) did a cross-sectional study that examined neighborhood-level walkability and safety around 73 public elementary schools in Austin, TX using a GIS. In their findings, the authors state that economic and ethnic conditions can create disparities in environmental support for walking. For example, in Hispanic communities, although road infrastructure is more walkable, there are still social issues that exist such as crime that are detrimental to walkability. This article can be used to guide the selection of parameters as well as the extraction of walkability variables.

This study helps district users not only consider the area that they are studying but also the population that they are serving.

A district should examine models comparing route directness. Bejleri et al. (2011) use ArcGIS to analyze children’s walk to school. They demonstrate how walking to school is a factor of path distance that is influenced by barriers and facilitators. In the study, the authors compare pedestrian sheds, or areas encompassed by the walking distance from a town or neighborhood center (often covered by a 5-minute walk of about 0.25 miles, 1320 feet, or 400 meters), from 32 randomly selected elementary schools within four Florida counties. Two measures from each shed were compared: the pedestrian route directness index and the student count in each shed. This study would be useful in a general school walkability model since the authors have done research in some of the standard measures and parameters such as the ½ mile (or 10 minute) threshold for elementary school student walks. However, the study uses a lot of data that is not accessible for this thesis project for the Chula Vista Elementary School District (CVESD), such as student addresses. This research was significant, because the user can see how certain road features can create an obstacle for students walking to school. For instance, barriers such as crime and traffic on a road may prevent students from walking down a certain path; therefore, the student will have to find another route along a network.

Data models help school districts in the collection of Safe Routes to School data. Huang and Hawley (2009) created a data model for a Safe Routes to School program in Flagstaff, Arizona. This data model relies on regularly updated data collected as volunteered geographic information (VGI) and crowd-sourced through a web GIS. This article can be used to establish principal types of data that will be collected. This data model uses 56 different variables that could be used for various analyses. For project constraints and the purpose of CVESD model, fewer variables will be collected as it will rely only on existing sources of professional GIS data, rather than VGI. Further, user collected data, such as walking audits expend a lot of time and resources. Students will typically draw maps of their route to school that can then be digitized (Safe Routes to School National Partnership 2017). Instead, it may be more beneficial and simpler for a school district to use openly available data.

There are many types of models that exist; the model described by Huang and Hawley (2009) does not have any weighted index or routing analyses, but is instead solely a data model. Reviewing a data model such as this can help a district user consider which variables are necessary and important and which variables are helpful, but can possibly complicate the model with extraneous data. Huang and Hawley had classified their data as roadway, intersection, and regional data. There were 29 regional variables, 17 roadway variables, and 16 intersection variables. Many of these variables such as land-use mix, dead-end density, and slope help to model walkability in general; however, the variables that would indicate safety such as crash records, crime rate, signalized intersections, and road type also would be beneficial in a model to find the safest route.

The variables selected for this model were variables that can be input as barriers within Network Analyst. Crime, one of the regional variables, can be input as a polygon barrier. Road characteristics, such as road class, can be input as a polyline barrier. Intersections can be input as point barriers. This can be further classified by the type of intersection. For instance, Yu (2015) examined two-level built environments (road environments and census tracts) related to the probability of severe injury for pedestrians throughout the City of Austin. In the study, Yu discovered that pedestrians were 98% more likely to get injured in a non-signalized intersection.

In building a model, signalized intersections can be weighted differently than non-signalized intersections.

Often times, when people commute, they are finding the path of least resistance. Walking to school is essentially finding the path of least resistance over an area. Guo and Ferreira (2008) investigate pedestrian friendly paths using six binary logit models in a GIS. They find that "friendlier" paths, or paths with less impedance, are more desirable for people to walk on even if they involve somewhat longer walks. District users can use this model to guide building a framework for SRTS. The walk to school is essentially finding a path with the least impedance. Impedance will influence the choice of path that the student takes. The environment in which the student walks affects the student's walking behavior and route choices.

All of these models help provide a framework for modeling in Chula Vista. However, the methods will vary in terms of tools and users. The district user should be cognizant of collecting the most helpful data, selecting the appropriate model that best describes the process of walking to school, and building a sustainable and lasting framework.

2.3 GIS Automation

Automation helps the development of technology by eliminating time-intensive tasks. A survey of middle managers in Montreal (Millman and Hartwick 1987) showed that automation made work more "enriching and satisfying." Automation can save people from having to complete long, tedious, and repetitive tasks. Programs and applications help to automate such tasks.

Embedded in ArcGIS are many tools that a district user can use to help make tasks go more quickly and smoothly. Arjun Rattan et al. (2012) used Modelbuilder 9.3 to model walkability for Ontario, Canada. They stated "ModelBuilder, in particular, enables project repeatability while minimizing project completion timelines." Although Arjun's project and ArcPy scripts produce repeatability, customizations still must be made in order to use these models in another application. Creating a model does not always ensure a universal application. Models can range from very simple to very complex.

Although Python scripting and GIS automation tools have been rarely used with Safe Routes to School, they have been used in many other fields. Etherington (2011) has used Python based GIS tools to visualize genetic relatedness and to measure landscape connectivity. Qichang Chen et al. (2008) have used automation for massive data collection to improve workflow performance. Daoyi Chen et al. (2008) have used automation in water resources management in developing countries. Roberts et al. (2010) have used geoprocessing tools in ArcGIS, Python, R, MATLAB, and C++ for an ecology study. Automation has mostly found success in more rigid sciences. The social science and education sectors may have been slower to adapt these technologies, because usually those in the field have different skillsets that rely more on the analysis of information rather than the automation. Nevertheless, automation could speed up that analysis process.

Overall, the study of automation is important for building a GIS framework for Safe Routes to School. Automation helps not only in project management but it can also contribute to the sustainability of the project. Automation helps districts not expend a lot of time training or repeating tedious tasks. Application development is a continuous process and a district user must consider the workload in the future. Building a GIS framework for Safe Routes to School should consider automation even if it is not done right away due to tool constraints. For instance, the Network Analyst extension does not run in Modelbuilder. But, building a model that can easily be automated will help with replicability in preparing data for use with Network Analyst.

Usually, simpler models can be more easily replicated; therefore, it is best practice to identify key variables to achieve the intended application. If the model will find the safest route, key safety variables and means of processing them will need to be identified. Further, although Network Analyst is not compatible with Modelbuilder, preliminary processing and data preparation can be completed with Modelbuilder.

2.4 Conclusion

Designing a model of the safest route to school requires a background of the SRTS program, understanding of the challenges for walking in real-world environments, and proper selection of appropriate models to fit the intended SRTS application. With GIS, Safe Routes to School can not only encourage walking to school, but also helps to build the capacity for safer walking through data-driven decisions and modeling. Understanding that students may be deterred from walking as a result of problems arising in their environment helps in the selection of key variables for the model. To take a route modeling approach in a Safe Routes to School program essentially means avoiding unsafe elements that the student will come across during a walk.

Chapter 3 Methods

Modeling the safest route to school involved several tools and processes. First, a conceptual model of the safest route was made based on key findings of the literature review. The model defined the key variables necessary for a safe route. Data were collected to model the variables as a safe route and, in many cases, data were refined to be used in the model. Finally, procedures for processing and analyzing the data in the GIS were determined.

3.1 Research Design

Before modeling the Safe Routes to School, key variables were defined in a conceptual model. The conceptual model enumerates the characteristics and processes that would make up a safe route. Using ArcMap 10.4.1 and its Network Analyst extension as equipment, data were collected as variable indicators, processed to create inputs for network analysis, and finally modeled across sample routes to make maps of the safest routes to school.

3.1.1. *Qualities of a Safe Route to School*

As covered in Chapter 2, route safety is dependent on minimizing the exposure to unsafe elements. Therefore, in general a safe route would be the shortest distance route. Beyond that, however, some increase in length might be allowed in keeping with a desire to avoid certain characteristics or prefer others. Avoiding the following specifications might lengthen routes: high crime areas, road intersections, areas of high collision exposure, areas of high traffic exposure, and freeways. Preferring the following specifications might also lengthen routes: local roads and intersections with crossing guards. Real world phenomena, like Safe Routes to School, often have a large number of variables that are hard to capture as a finite number of indicators.

The variables selected here were determined to be principle components of a safe route to school based on recurring themes within literature review.

3.1.2. *Variables*

Variables for this tool required the use of several data sets. The variables can be generalized as network variables and safety variables.

Network data are comprised of the destinations (school sites), origins (residential parcels), and roads that students would traverse. Routes were found along a road network dataset. The road data let us know a variety of road factors such as whether a road was one-way, the speed, and the segment classification. Each segment has its own characteristics or attributes; these attributes describe the overall environment. Students will travel through the network to and from the school and the residential parcels.

Safety variables were fit into the model as network attributes and travel barriers. As mentioned, the road data had several attributes; some of which were also used as safety variables. The type of road classification was a major indicator of road safety. For instance, a student would not walk down a freeway, mostly avoid major roads, and prefer local streets because there is less traffic and exposure to cars. This classification can be used in a travel hierarchy from least traffic exposure to most traffic exposure. However, the road hierarchy had little effect on the routing in Network Analyst, so a hierarchy was not created in Network Analyst. Instead, restricted routes such as freeways and on-ramps were input as restricted barriers.

Barriers add or lessen the cost of traversing a route along a network. Barriers can be modeled as points, lines, or polygons. Although the term “barrier” has a negative connotation and one would think it would apply only to avoided features, it was applied to the supportive features such as walkways and crossing guards to match the nomenclature within ArcMap. Whether a feature is to be preferred or avoided, they are all called “barriers” within the Network Analyst extension. Safety variables act as obstacles and measures of travel impedance.

3.1.2.1. Point Barriers

Points are one type of barrier within Network Analyst. After passing through a point on the network, Network Analyst adds a cost to the segment length. Points are suitable to represent characteristics of intersection such as whether crossing guards are present. As the road network had been simplified as a polylines, intersections were simplified as points, which were added to the line.

3.1.2.2. Line Barriers

Lines are the second type of barrier within ArcGIS. They need to intersect the network at one or more points to affect cost. The cost is multiplied based on the length of the impacted segment in a scaled cost or can be restricted entirely. Line barriers are effective in defining classes of road that are most and least safe.

3.1.2.3. Polygon Barriers

Polygon barriers are the third type of barrier. They add a scaled cost to the roads that pass through them. These are helpful when using data that is not described by the road network but instead as a characteristic of the area. Examples in this study include crime hotpots or buffers from pedestrian traffic incidents.

3.2 Data Selection and Sources

Multiple sets of data were required to build the safe route framework. Data were collected from the San Diego County Association of Governments, San Diego Regional Data Library, UC Berkeley Transportation Incident Mapping System (TIMS), the City of Chula Vista, and digitized school district maps. Most of the data were originally collected for a different use. The data were evaluated for fitness of use for this project. In many cases, further processing of the data was required to integrate components into the Network Analyst extension. In general, data were separated into several feature classes from a few datasets. Similar data were collected from each school site. Table 1 generally describes how the data indicates each safety factor. Each data set was projected into the same projected coordinate system for analysis.

Table 1 Safety indicators and associated data

Factor	**Data**	**Source**	**Description**
Avoid high crime areas	Barriers - Crime	San Diego Regional GIS Warehouse (SANGIS)	2007-2013 Esri shapefile points with crime data
Prefer crossing guards	Barriers - Cross Guards	Collected Data; Drawn Points	Esri shapefile points with crossing guard locations
Avoid freeway	Barriers - Freeways	San Diego Association of Governments (SANDAG)	Selection of Roads
Avoid intersections	Barriers - Intersections	SANDAG	Esri shapefile
Avoid areas of high collision exposure	Barriers - Traffic	UC Berkeley Transportation Incident Mapping System	2010-2015 traffic data (CSV) with traffic incidents
Reference Network Data	Roads	SANDAG	Esri shapefile polylines with Road data and attributes
Reference Network Data	School Zone	Drawn polygons from district's listing of streets within the school zone	Esri Shapefile polygon of the school zone boundaries
Reference Network Data	Stops - Parcels	SANDAG	Esri shapefile with point parcels
Reference Network Data	Stops - Schools	SANDAG	Esri shapefile with school points
Avoid intersections	Traffic Signals	City of Chula Vista	Esri shapefile with traffic signals
Avoid areas of high collision exposure	Traffic Signals	City of Chula Vista	Esri shapefile with traffic signals

The table below has a summary of the preparations and processing, which will be detailed further in subsequent sections.

Table 2 Data processing procedures

Data	**Processing**
Barriers – Crime	*Create hotspots for polygon barriers; Select only hot spots with 90% significance (Z-Score > 1.65) *Add polygon barriers to network analyst route (scaled cost)
Barriers - Cross Guards	*Add to network analyst route as a point barrier (scaled cost)
Barriers - Freeways	*New layer from Roads *Add as a restricted polyline barrier in network analyst route
Barriers - Intersections	*Clip only roads from school zones *Select only Intersection ("I") attributes and Create New Layer *Separate signalized versus non-signalized intersections *Add to network analyst route as a point barrier (scaled cost)
Barriers - Traffic	*Select only pedestrian collisions *New layer from pedestrian collisions *Buffer: 150-feet *Add to network analyst route as polygon barrier (scaled cost)
Roads	*Clip only roads within school zone boundaries *Add new field and reclassify roads into a hierarchy *Build network dataset *Use attributes in hierarchy for network analyst route
School Zone	*Create polygon in Editor Mode *Use boundaries to define study area and to clip other features
Stops – Parcels	*Select residential parcels only *Use in network analyst route as origin or destination
Stops – Schools	*Select schools in study areas *Use in network analyst route as origin or destination
Traffic Signals	*Spatial join with intersections *New layers with signalized versus non-signalized intersections *Input as scaled cost of intersection point barriers

3.2.1. *Roads*

Roads were the principal data for the network; these are the route infrastructure that students would travel through. The roads in the study area all had sidewalks because of the generally urban environment in the Harborside neighborhood and newly designed Wolf Canyon neighborhood, so it was not necessary reclassify roads with sidewalks in the cost weighting. Preexisting data on the sidewalks had not existed. If necessary, the sidewalks would need to have been digitized. Roads were collected from the San Diego Association of Governments Regional Data Warehouse’s county roads shapefile. The format came in a set of polylines (i.e., as a vector format in an Esri Shapefile). The units of measurement were miles. This shapefile contains all roads within San Diego County. Road segments were defined as lines between intersection and jurisdictional boundary points. The extent was within the San Diego County region. The projected coordinate system (PCS) used was NAD_1983_StatePlane_California_VI_FIPS_0406_Feet. There are 65 attributes for each road segment such as the road names for directions, length for travel costs, and the classification for road hierarchy.

3.2.1.1. Fitness for Use

There were a few criteria that were used to determine whether this data set was fit for use. This dataset comes from a credible source and is updated frequently. It was last updated on March 7, 2016 (on-going update). A variety of sources were used for the development and ongoing maintenance of the major roads feature class. Source data includes San Diego County Roads, Caltrans State Highway Centerlines, and street centerline data from Imperial County. Regional aerial imagery (1-foot pixel resolution or better) was generally used as a guide for delineating roadway alignments, primarily using heads up digitizing methods in ArcGIS. This data was ideal for local analysis.

3.2.1.2. Processing

The roads data required further processing to be used in the model. Roads were clipped to the study area from shapefiles provided by SANDAG (San Diego County Roads shapefile to school zones). This sped up processing times as the data originally was encumbered with all the roads in San Diego County. The road shapefiles were used to build network datasets around each school site by right-clicking the shapefile and selecting the build network dataset option in ArcCatalog. Length was selected as the travel cost parameter, because the students will walk at different paces and travel time cannot be determined. With the network built, the data was ready for network analyses.

3.2.2. *School Zone*

The school zone was needed to determine the maximum area where students will walk from. The school zone shapefile was created by drawing a polygon using the Editor tool. Boundaries were determined by a list of Harborside and Wolf Canyon streets listed on the 2016-2017 student placement assignment list.

3.2.2.1. Fitness for use

The school zone boundary was fit for use, because it was not used heavily in the analysis. Instead, it was used to determine the processing extent and to establish the areas that the school serves. The polygon was snapped to road features so that no polylines were missing from the analysis. The school zone boundary was used to clip road, traffic, and crime features. This helped lower processing time.

3.2.3. *Stops – Schools and Parcels*

"Stops" or locations where students will go to on their way to school were also included as network variables. The school and parcels were collected for stops. Most students will go straight to school, so the stops consisted of the school location and home location. Since home locations were inaccessible due to privacy concerns, a non-random sample of residential parcels located in various residential neighborhoods in different directions from the schools were used as hypothetical home locations to demonstrate the routing model.

3.2.3.1. Fitness for use

Each set of stops was evaluated for fitness of use separately. The data was examined in ArcGIS and the metadata was reviewed. The school site data was evaluated first. School site data came from a San Diego Association of Governments (SANDAG) shapefile called "SCHOOL_POLY." This polygon contains public and private school sites, including elementary, middle, and high schools. The metadata states that it was last updated on November 19, 2015 (annual update). The extent was within the San Diego County region. The PCS used is NAD_1983_StatePlane_California_VI_FIPS_0406_Feet. The attribute table had 1200 records. This contains the following fields: FID, CDSCode, District, School, Street, City, ZIP, OpenDate, Charter, DOCType, SOCType, GSoffered, ShortName, ID, Priv, Shape, Shape_Area, and SHAPE_LEN. This dataset came from a credible source and was updated frequently. This data was fit for analysis.

Next, the parcel data was evaluated. The parcel data was a polygon shapefile from SANDAG as well. It was classified based on land use type and only the residential parcels were selected. The metadata stated that it was collected on a weekly basis. The PCS used is NAD_1983_StatePlane_California_VI_FIPS_0406_Feet. Like the school data, this dataset came from a credible source and was updated frequently. This data was also fit for analysis.

3.2.3.2. Processing

Both the school sites data and parcel data required processing before they could be used. Harborside Elementary and Wolf Canyon Elementary schools were selected from a shapefile with all the schools in San Diego County. Each was exported into its own shapefile. The parcels were clipped using each school zone, and then residential parcel features were selected and converted to points on the centroid of each parcel. Both the school points and residential parcel points were included as origins and destinations. These were added in as parameters when creating a route in the Network Analyst toolbar. In the Network Analyst route options, the search bandwidth was set to 5,000 meters. Within this bandwidth, the points snapped to the nearest road segment for analysis.

3.2.4. *Traffic*

Traffic data was an essential variable to use as a polygon barrier in the network. Students will avoid areas where there have been pedestrian collisions in the past. Traffic came as a CSV file with traffic incident points from UC Berkeley's Transportation Incident Mapping System (TIMS).

3.2.4.1. Fitness for use

There were several items observed to determine fitness of use for the traffic data. The time range represented January 1, 2010 – December 31, 2015. This CSV file was downloaded and georeferenced based on coordinates provided for each incident. The original file contains the longitude/latitude coordinate locations based on the 1984 World Geodetic System (WGS84), so it was re-projected to match the state plane projection used for this study. The points fell on road segments. Incidents were located directly at an intersection or within the center of the block. The data was appropriate because it was the most recent set of data freely available. This data also contained attributes such as whether a pedestrian was involved in a collision and severity of collisions. Even across five years of data, there were not enough severe collisions and total collisions to produce a hotspot analysis. Therefore, polygon barriers were created using just the pedestrian-involved collision points with buffers. There were 42 pedestrian-involved collisions in the Harborside neighborhood and 0 incidents recorded in the Wolf Canyon neighborhood. The zero incidents is likely a result of Wolf Canyon being a newly built neighborhood and the provisional, or not finalized, status of the data.

3.2.4.2. Processing

This data set required processing for use. The CSV file was converted to an Esri shapefile. The traffic incidents were projected to the NAD_1983_StatePlane_California_VI_FIPS_0406_Feet PCS. The traffic points were clipped using the school zone boundaries for each study area. The pedestrian collision attributes were selected and separated into a new feature class. This feature class was buffered by 150-feet in order to cover the length of the average intersection. These buffers were added as scaled-cost polygon barriers in Network Analyst where students can cross them but at an added cost.

3.2.5. *Crime*

Crime data was used for another polygon safety barrier. Crime data came as points in a shapefile from San Diego Regional Data Library. The time frame for the data used was January 1, 2007 – March 31, 2013. Unfortunately, there was no metadata; however, the website stated, “this dataset includes geocoded crime incidents from 1 Jan 2007 to 31 March 2013 that were returned by SANDAG for Public Records request 12-075” (San Diego Geographic Information Source 2014).

3.2.5.1. Fitness for use

Several methods were used to evaluate the crime data’s fitness for use. Due to its size and detail, this data appears credible. The crime points were clipped using the school zone boundaries for each study area. The whole dataset was used to provide enough crime incidents to perform a hotspot analysis. In the attribute table, there were 1,514 records. There were 13 types of crime. Most crimes are “THEFT/LARCENY” (417). The directional distribution in the Harborside study area is slightly from northeast to southwest. The median center was more east than the mean center, signifying that there was more clustering towards the east side of the data. Wolf Canyon’s directional distribution was slightly northwest to southeast with median center north of the mean center. There was a severity associated with the crimes, but there were not enough severe crimes to be used with the ArcMap hotspots tool. To get valid hotspot results, all reported crimes needed to be taken into account. The points all seem to fall on road segments; however, polygon hotspots were created because the project seeks to describe neighborhoods in the study areas with higher than expected crime, rather than line features. The data was geocoded based on street and block number. The detail and source of the data made it fit for use.

3.2.5.2. Processing

The crime points also required processing before use. The crime points were projected to the NAD_1983_StatePlane_California_VI_FIPS_0406_Feet PCS. The Optimized Hotspot Analysis tool was used to find statistically significant hot spots or areas with high likelihood of crime. This tool interrogates data to obtain the settings to yield optimal hotspot results. If the input features contain incident point data, the tool aggregates the incidents into weighted features. Using the distribution of the weighted features, the tool identifies the appropriate scale of analysis. This was selected over the Getis-Ord Gi* Hotspot Analysis, because the Getis-Ord Gi* requires multiple tests in order to determine the correct parameters (Esri 2017). The Optimized Hotspot Analysis tool is more practical for a school district’s project management constraints. The tool automatically selected the optimal pixel size of the study area and found significant clustering of crimes on the output raster map along with an output table. No weighting was selected in the tool parameters, because there were not enough severe crimes for such analysis. The tool reported a cell size of 228 meters; the optimal fixed distance band is based on peak clustering found at 530 meters. The aggregation process resulted in 81 weighted polygons. From the output map, areas with a Z-Score greater than 1.65 were selected and made into a new feature class. These areas were hot spots with a statistical significance greater than 90% indicating that these were likely areas of crime clustering. The selected polygons were added to the Network Analyst route layer with a scaled cost.

3.2.6. *Intersections*

Intersection points were used in the analysis, because these are points where students will be exposed to traffic. Intersections should generally be avoided; however, there is a hierarchy of intersections where signalized intersections are safer than non-signalized intersections. The intersections also came from SANDAG as an Esri point shapefile. They were made from the intersect points after creating a new network dataset in ArcGIS and adding jurisdictional boundaries as part of the points. The intersections were clipped using school zone boundaries. The points coded as intersections (“I”) were selected as attributes into their own feature class. Intersections that were spatially joined with traffic signals and those that were not were added to separate feature classes to be input as barriers with different costs.

3.2.7. *Crossing Guards*

Crossing guard data was geocoded based on field observation. In general, the crossing guards were placed at intersections. The intersections where crossing guards were recorded as points and then these points were digitized into a new layer. These were input into the GIS as a point shapefile. The presence of traffic guards increases the amount of safety down the network. They help students to cross intersections and increase the awareness that students are present.

The crossing guards at the intersections reduces the added cost of the intersection leading to an overall lower scaled cost in the route analysis.

3.2.8. *Park Walkway*

The Wolf Canyon elementary school was adjacent to a park. The park was a safe area for students to pass through, because traffic does not flow through the park. A sidewalk went through the park originating at one intersection and ending at another. This park walkway was digitized and added to the network route layer as a line barrier with a low scaled cost to encourage students to take this route.

3.3 Procedures and analysis

After the data was collected and preprocessed, the model was ready to be set up. The model will find routes with the least cost of impedance. Impedance is a measure of the amount of resistance, or cost, required to traverse a path in a network, or to move from one element in the network to another. Essentially, this is finding the path of least resistance or the optimal path based on what was being measured. Figure 2 has the basic framework of the overall process.

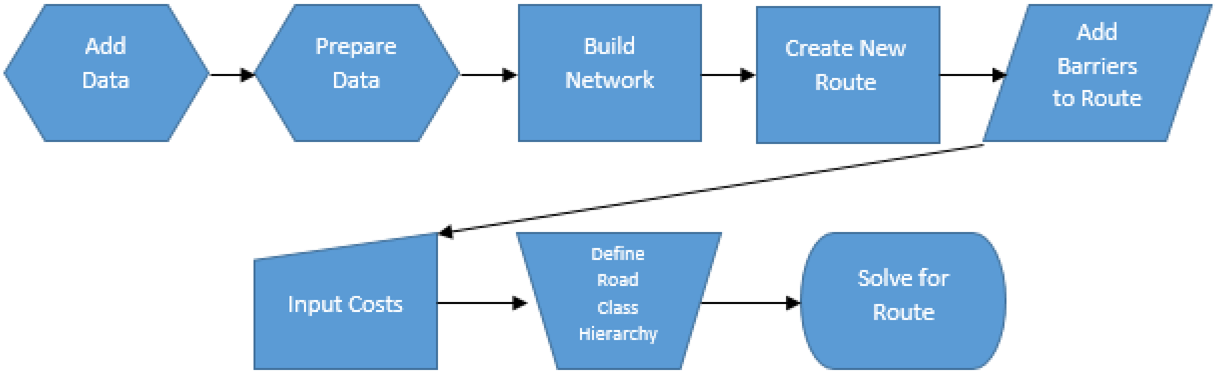

Figure 2 Process overview

3.3.1. *Route Layer*

After the network dataset was built and the required data were prepared for network analysis, the new route layer tool was selected in the Network Analyst tool bar. The route tool will find routes of least impedance based on the specifications and parameters input into the network layer. The length, or cost, of the road segment is added to or lessened based on the types of features that the student will traverse in the network. A scaled cost is multiplied to the network length for points, lines, and areas unless the area is designated to be restricted entirely. For restrictions, Network Analyst avoids the network segment entirely. Creating road hierarchy can determine the preference of roads that the students will travel across; however, as noted earlier, a road hierarchy was not necessary in this model. Figure 3 below describes the detailed Network Analyst route creation process for this study.

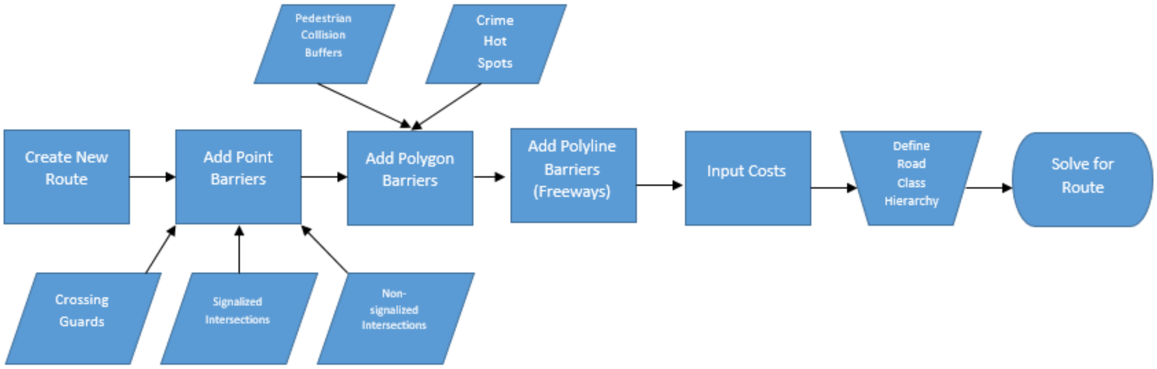

Figure 3 Network Analyst process detailed

3.3.1.1. Stops

Stops were added to the network analyst. These were the beginning and ending points of each route. The school was chosen as the start point and the parcel was chosen as an origin and destination. To achieve this, the “Stops” line was selected on the “New Route” analysis layer. The “Create Network Location” button was selected to choose routes. Each route layer had two stops: the school and a parcel from each neighborhood.

3.3.1.2. Barriers

Barriers are areas on the network that add or, despite the counterintuitive nomenclature, lessen impedance. To add barriers, locations were loaded and scaled costs were chosen. One is the standard segment length. Anything greater than one increases the scaled cost and is therefore less safe. Anything less than one decreases the cost and is safer. As mentioned above, “restricted” barrier types do not allow for travel through an area. There were three types of barriers as mentioned earlier: point, line, and polygon.

The point barriers added were the signalized intersections, non-signalized intersections, and the crossing guards. This was achieved by right-clicking “point barriers” in the route analysis layer, adding the data, selecting the option for scaled cost in “barrier type” field, and then adding the scaled cost score. Signalized intersections were given a scaled cost of 1.25 times the length of the segment. Non-signalized intersections were given a scaled cost of 1.5, and crossing guards were given a scaled cost of 0.5.

The line barriers added were the freeways and walkways. Right-clicking “line barriers” and selecting “load locations” in the route analysis layer allowed the line barriers to be added. The freeways and on-ramps layer was added with a “restriction” barrier type since no one is allowed to walk on the freeways as this is extremely unsafe. The walkways were added with a scaled cost type barrier. The scaled cost used was 0.25 since these walkways generally traveled through parks or areas where traffic cannot go entirely.

Finally, the polygon barriers were added by right-clicking the “polygon barriers” line and loading the pedestrian-involved traffic incidents and the significant crime hot spots. Since these areas were considered areas of danger and should generally be avoided, they were both given a scaled cost of 2. Table 3 has the selected parameters.

Table 3 Barrier costs

Variable	**Parameters**
Barriers – Crime	Scaled Cost: 2
Barriers - Cross Guards	Scaled Cost: 0.5
Barriers - Freeways	Restriction
Barriers - Intersections	Added Cost (Non-Signalized): 1.5 Added Cost (Signalized): 1.25
Barriers – Pedestrian Collisions	Scaled Cost: 2
Barriers – Walkways	Scaled Cost: 0.25

3.4 Analysis and Conclusion

This modeling will compare safe routes from the two different school sites. In order to achieve this, multiple routes were created from each school sites and parcel samples from the different residential neighborhoods surrounding the school sites. The samples were selected to be representative of each neighborhood area within the school zone. Single family residential and multifamily residential parcels were selected from the land use data and used to locate the residential neighborhoods within each study area; next a random parcel was selected from each residential neighborhood in the school zone. The routes were compared by the safest route distance, shortest route distance, and safest route cost-weighted distance.

There were different procedures to find each distance. The goal was to be able to compare the shortest route to the safest route, and to measure their distances to see how much they deviate. This was based on the principle mentioned above that shorter routes are generally safer, so that the model should be regulated such that any deviation from the shortest routes would be minimal and introduced for evidently good reasons. The safest route cost distance automatically came up in the route attribute table once the “solve” button was selected. To find the shortest route distance, the route layer was copied, barriers were removed, and the route was resolved without the barriers. To find the safest route *distance,* a new feature class was created using the “create route” tool and selecting the safest route from the completed safe route analysis. The safest route distance was found in the attribute table of the newly created route.

Once each route was solved, the results from each layer were ready to be collected. As a recapitulation, data were processed by building networks, creating a new route analysis layer, adding scaled point, line, and polygon barriers, defining a road hierarchy, and solving for the safest and shortest routes. The results compare shortest and safest routes to school between a sample of residential locations and the Harborside and Wolf Canyon elementary schools.

Chapter 4 Results

The network analysis resulted in maps of the safest and shortest routes to school and their corresponding attribute tables. Results allow comparison of safest and shortest distances for hypothetical set of routes at each school site. The analysis also derived a cost-weighted distance which was the product of the Network Analyst algorithm. There were five routes from each school site to non-randomly selected parcels totaling to ten routes in whole. Table 4 below has a summary of the results.

Table 4 Route distances

Route No.	School	Parcel ID	Shortest Distance (Ft)	Safest Distance (Ft)	Safest Cost Weighted Distance (Ft)
1	Harborside	382499	4,810	4,820	10,940
2	Harborside	555229	7,720	8,250	10,770
3	Harborside	29042	5,260	5,670	7,880
4	Harborside	425166	1,580	1,760	1,870
5	Harborside	55975	3,490	3,490	4,510
6	Wolf Canyon	5222871	8,550	9,560	10,540
7	Wolf Canyon	5256896	3,650	4,070	3,200
8	Wolf Canyon	5221394	6,580	6,670	5,810
9	Wolf Canyon	5297250	7,640	7,740	6,870
10	Wolf Canyon	5308320	10,320	10,420	9,550

Afterward, the mean was calculated for each school zone (see Table 5). The means were calculated for the shortest, safest, and safest cost-weighted distances. Between the longest and shortest routes, there was a difference of 3,230-feet (shortest) and 6,480-feet (safest) for Harborside. For Wolf Canyon, the difference between longest and shortest routes was 6,670-feet (shortest) and 6,350 (safest). Wolf Canyon was a more sprawling area with fewer barriers. The shortest distances are longer, but the safest distances do not add that much more travel. The park walkway, which lowers the cost of travel, was generally not used in the calculation for the shortest route.

Table 5 Mean distances

School	Shortest Mean (Ft)	Safest Mean (Ft)	Safest Cost Weighted Mean (Ft)
Harborside	4,570	4,800	7,190
Wolf Canyon	7,350	7,690	7,190

Next, the mean difference was calculated between each school zone for the shortest, safest. In Harborside Elementary, there was difference of 230 feet between the safest and shortest mean distance. In Wolf Canyon, there was a difference of 340 feet between the safest and shortest mean distance (See Table 6).

Table 6 Mean differences

Route	Mean Difference
Harborside	230
Wolf Canyon	340

The mean difference between the shortest and safest distance remained close with the safest distance being slightly higher in both study area. The costs were configured so that the safest distance did not divert from the shortest distance by more than 10%. There was only a 4% increase between the shortest and safest mean difference. The cost-weighted distance difference totaled to 0 between Wolf Canyon and Harborside. Wolf Canyon had a lot fewer impedances and therefore lower weighted costs were anticipated. Even though Wolf Canyon routes tend to me longer, the option or a park pathway resulted in credits that actually made the cost-weighted shorter than the shortest distance.

4.1 Harborside Results

The Harborside Elementary school zone was the first area to be analyzed. As a reminder, Harborside Elementary School was the lower social and economic status (SES) school on the west side of Chula Vista. The neighborhood was older and more urban. Figure 4 displays a map of the barriers within the overall area. Each analysis will output routes that avoid these barriers.

Figure 4 Map of Harborside school zone and barriers

How each route varied will be detailed more in subsequent sections. Each parcel and its location will be described. Where the safest route changed from the shortest route will be further detailed.

4.1.1. *Harborside Route 1*

Route 1 connects Harborside Elementary School to Parcel 382499. The parcel is located at 470 Shy Lane, in the east side of the school zone. The shortest route measured at 4,900-feet. The safest route was at 4,820-feet. The cost weighted safest distance was 10,940-feet.

The safest route varied from the shortest route by going through Naples and skipping over Broadway. The safest route and shortest route converge in on Fifth Ave. But by staying on 5th Ave and diverting the route from Broadway, the safest route misses a long stretch of five crime hot spots. As the routes diverted, each route went through four intersections. The safest route passes through more pedestrian collisions in total than the shortest route. However, on balance, it has a lower cost weighting because of the missed crime hotspots. The model weights the major areas of crime heavily, because the distance of the line segments for the safest route running through the scaled cost barriers for pedestrian collisions was less than the distance running through the crime hotspots for the shortest distance (see Figure 5).

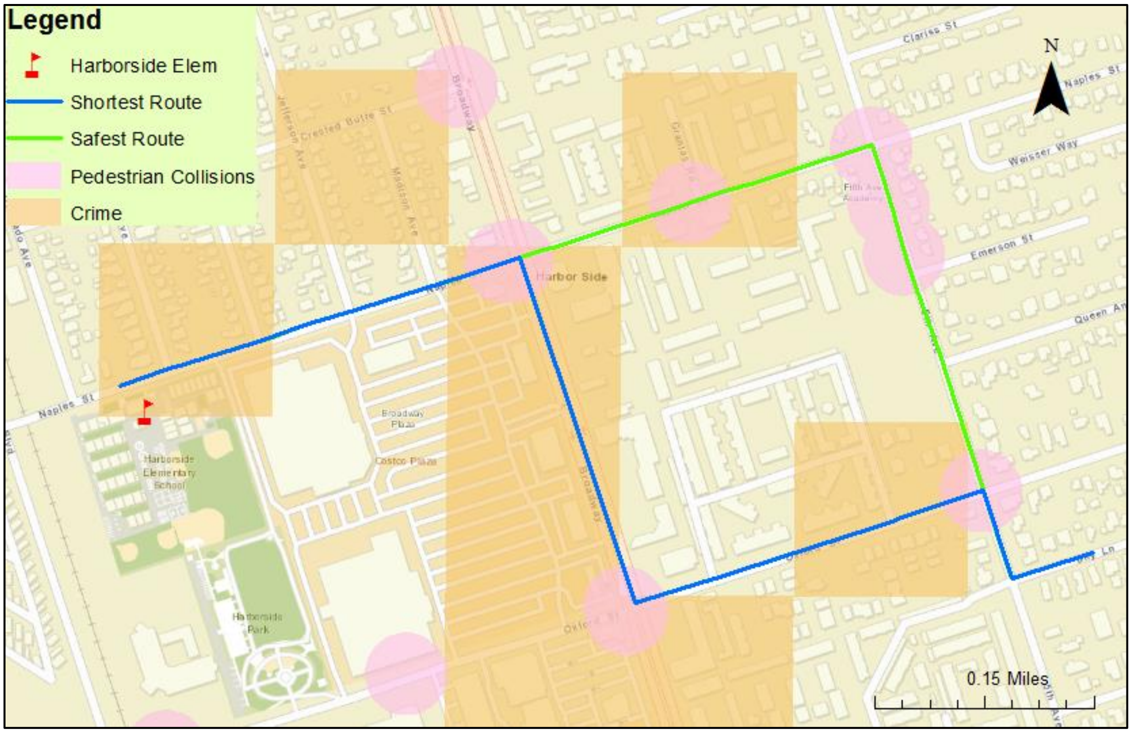

Figure 5 Harborside Route 1

4.1.2. *Harborside Route 2*

Route 2 connects Harborside Elementary School to Parcel 555229. Parcel 555229 is located at 473 Anna Linda Pl in the southeastern part of the school zone. The shortest route measured at 7,720-feet. The safest route measured 8,250-feet. The safest cost weighted distance was 10,770-feet.

The safest route went west towards Industrial Blvd instead of going east and turning on Broadway. By missing Broadway, the safest route missed all of the crime hot spots and instead bypassed only three pedestrian collisions. The safest route also passed through six fewer pedestrian intersections. The shortest route passed through eighteen while the safest route passed through six. The safest route passed through one crossing guard while the shortest route passed through all four crossing guards. Although the shortest route had students pass through various crossing guards which were meant to lower the overall distance, the scaled cost of the crime and pedestrian collisions added a lot more additional costs. Thus, the network analysis produced a path that diverted the polygon barriers altogether (see Figure 6).

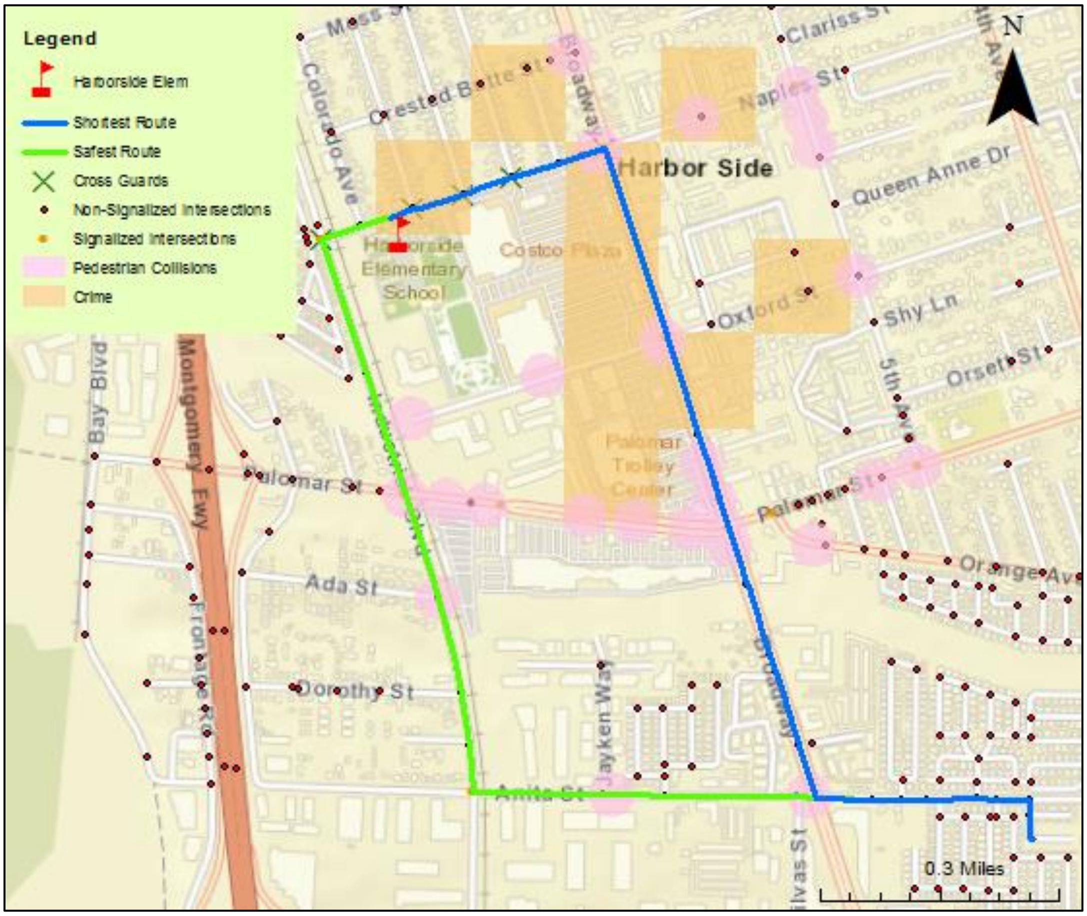

Figure 6 Harborside Route 2

4.1.3. *Harborside Route 3*

Route 3 connects Harborside Elementary to Parcel 29042. The parcel’s location is 911 Fifth Avenue in the northeast of the school zone. The shortest route measured at 5,250-feet. The safest route was 5,670-feet. The safest cost weighted distance was calculated as 7,880-feet.

The safest route went west on Naples, up north on Colorado Ave, east on Crest Butte Ave, and north on Wood Lawn Ave before running into several barriers. By diverting the route, the safest route bypassed one pedestrian collision and crime hotspot in front of the school. The shortest route went through two crime hotspots. In the common hotspot in front of the school, the shortest route traversed a greater distance. The safest route passed twelve intersections; the shortest route passed eleven intersections. The areas in front of the school had a lot of crime reported; therefore, the model directed students away from that, but converges routes closer to the parcel in an area with little crime (Figure 7).

Figure 7 Harborside Route 3

4.1.4. *Harborside Route 4*

Route 4 connects Harborside Elementary to Parcel 425166. Parcel 425166 was located at 1008 Woodlawn Ave in the neighborhood just north of the elementary school. The shortest distance was 1,580-feet while the safest distance was 1,760-feet. The safest cost weighted distance was 1,870-feet.

The safest route went east on Naples and north on Colorado instead of east on Naples and directly north on Woodlawn. The safest route went through four intersections while the safest route went through three intersections. The shortest route passed through one crossing guard; however, less than half of the shortest route passed through a crime hot spot. Both routes only passed through one crime hot spot, but the model calculates based on the length of the line segment running through the polygon barrier, so it diverted the path to minimize the length of the path running through the polygon barrier area (Figure 8).

Figure 8 Harborside Route 4

4.1.5. *Harborside Route 5*

Route 5 connects Harborside Elementary to Parcel 55975. This parcel was located at 1225 Frontage Road in the mobile home park southwest of the school. The shortest distance and the safest distance were both the same at 3,490-feet. The cost weighted safest distance was 4,510-feet.

In this case, the shortest and the safest routes followed the same path going west on Naples, south on Industrial Blvd, west on Palomar, and south on Frontage Rd. Both routes passed through one pedestrian collision, one crime hot spot, one crossing guard, and eight intersections. The route went along the same path, because there were not enough barriers to divert the safest path, and the barriers that each path crossed could not be avoided in the case of the intersection between Palomar and Industrial. There was only one way for the students to go; otherwise, Network Analyst would gone a lot further to the nearest safest path. It was possible for the shortest and the safest path to be the same if there are not any barriers that would add enough costs to the safest paths and/or there is a corridor that dominates the path (Figure 9).

Figure 9 Harborside Route 5

4.2 Wolf Canyon Results

The network analysis also resulted in map and attribute table outputs in the Wolf Canyon Elementary school zone. These results were expected to remain similar between the shortest and safest routes as the area did not have as many barriers. The school's service area was larger and had a higher SES population than Harborside. The Wolf Canyon school zone overlapped slightly with the Veterans Elementary school zone. Construction around Veterans Elementary began as the school was already near capacity, so Wolf Canyon was assigned as an overflow school for extra students until the new elementary school is built. It was also newly built, encompassing both suburban and rural communities. Again, each analysis outputted maps of the shortest and safest routes to school. The paths often converge after the park walkway, because the area is larger and with fewer barriers where students should avoid. The intersections were not weighted heavily enough to divert the path (Figure 10).

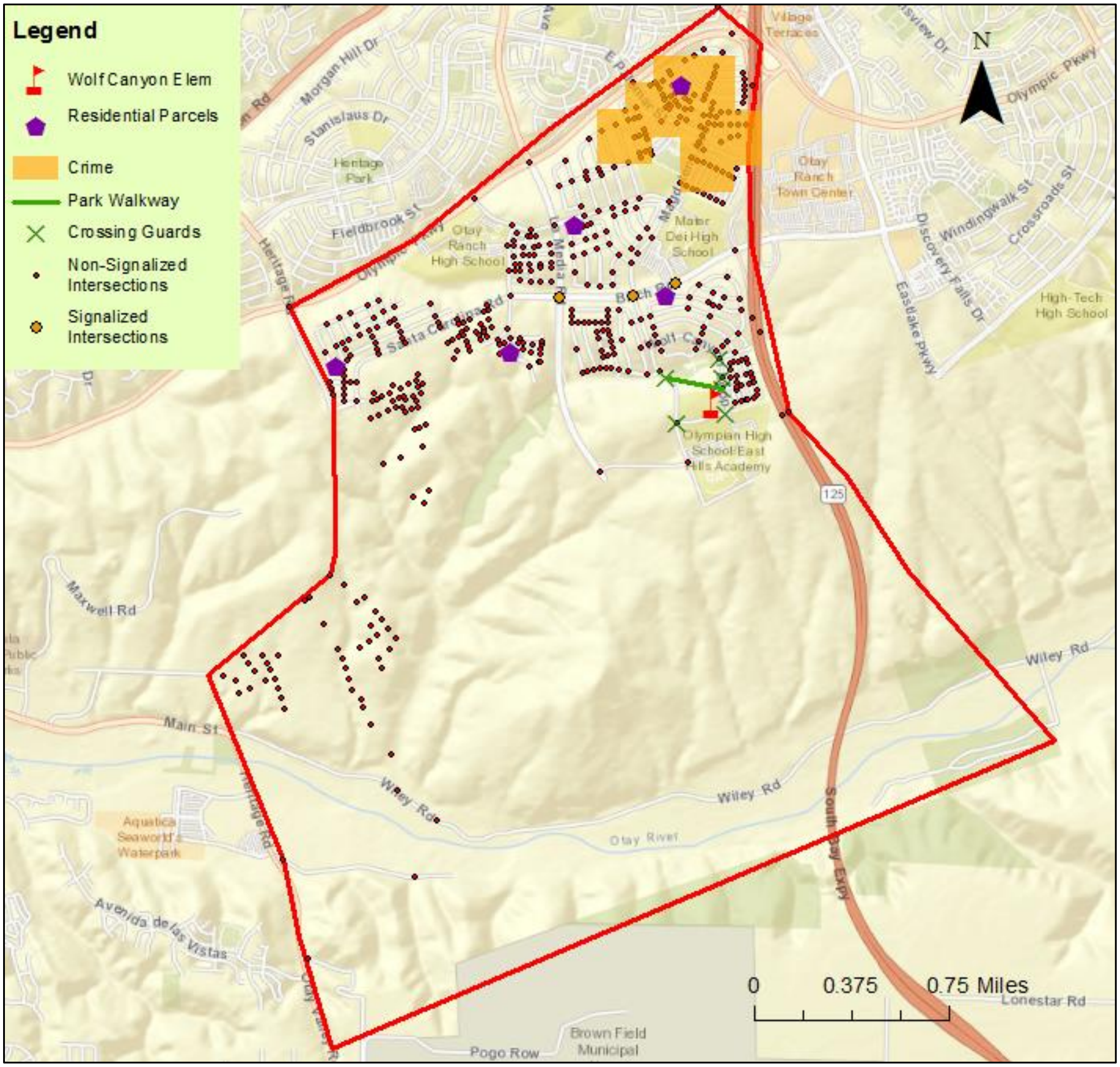

Figure 10 Wolf Canyon study area and barriers

4.2.1. *Wolf Canyon Route 6*

Route 6 connects Wolf Canyon Elementary to Parcel 5222871. The parcel is located at 1360 Sutter Buttes Street on the northeast side of the school zone. The shortest distance was 8,550-feet. The safest distance was 9,560-feet with a cost-weighted distance at 10,540-feet.

The safest route had students walking through the park before bearing right on Magdalena Ave. From Magdalena Ave, students were routed to left on Trailwood Ave into a residential neighborhood in order to miss several crime hot spots. The safest route went through three crime hot spots while the shortest route went through six. The safest route passed three crossing guards; the shortest route passed two. The safest route had twenty-one intersections, and the shortest had sixteen. The route avoided the polygon barriers where the costs were much higher and added distance where the park walkway was much safer (Figure 11).

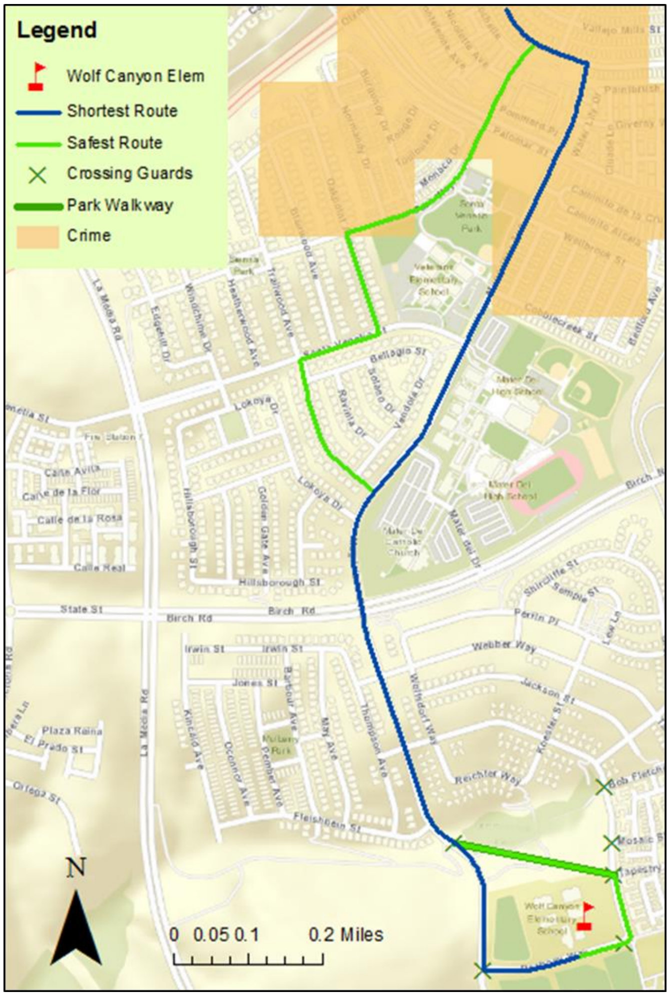

Figure 11 Wolf Canyon Route 6

4.2.2. *Wolf Canyon Route 7*

Route 7 connects Wolf Canyon Elementary to Parcel 5256896. The parcel is located in the neighborhood just north of the school at 1731 Perrin Pl. The shortest distance was 3,650-feet. The safest distance was 4,070-feet; however, the cost-weighted distance was 3,200-feet.

The safest distance had students go through the park trail while the shortest distance continued north on Wolf Canyon loop and through the neighborhood. The safest distance passed through three crossing guards; the shortest distance passed four. The shortest distance had 11 intersections; the safest had 8 intersections. No crime hot spots were passed through. Students were encouraged to safely walk through the park walkway and pass the crossing guards where the route had a lower scaled cost. Afterward, the routes converged where there were not any differences in the barriers (Figure 12).

Figure 12 Wolf Canyon Route 7

4.2.3. *Wolf Canyon Route 8*

Route 8 connects Wolf Canyon to Parcel 5221394. Parcel 5221394 was at 1528 Hillsborough Street. This parcel was northwest of the school. The shortest distance measured at 6,530-feet, and the safest distance was 6,670-feet. The cost-weighted distance was calculated at less than the shortest distance at 5,810-feet.

The safest route went through the park as did route 7. Both routes converged at Magdalena Avenue. Neither went through any of the crime hot spots. Both routes passed three crossing guards; however, the safest route went through the crossing guards on the southeast of the school while the shortest went through the southwest crossing guards. The safest route had fifteen intersections; the shortest route had fourteen intersections. This route produced similar results to Route 7 even at a longer distance; students went through the park walkway and crossing guards where the scaled costs were lower.

4.2.4. *Wolf Canyon Route 9*

Route 9 went from the elementary school to Parcel 5297250. This parcel was in the neighborhood to the east of the school district at 1573 Ortega St. The shortest distance was 7,640-feet. The safest distance was 7,740-feet. The cost-weighted distance was 6,870-feet.

Like Route 8, the safest route safest route went through the park trail before converging at Magdalena Ave. Again, the safest route had an extra crossing guard and intersection (i.e. the intersection had a crossing guard). There were fourteen intersections and three crossing guards for the safest route. The shortest route had thirteen intersections and two crossing guards. Neither route passed through any crime hot spots. This route produced similar results to route 9 in which there were few barriers in the school zone, so the route went through the crossing guards and walkway with lower scaled costs.

4.2.5. *Wolf Canyon Route 10*

Route 10 went from Wolf Canyon Elementary to Parcel 5308320. The parcel was located at 1589 Franceschi Dr. at the far west side of the school zone. The shortest route had a distance of 10,320-feet while the safest route had a distance of 10,420-feet. Again, the cost weighted distance was calculated as less than the shortest distance at 9,550-feet. The lower weighted costs is common in areas where there are not many barriers with an added cost.

Once again, the safest route took the park trail before converging with the shortest route at Magdalena Ave. Neither passed through any crime hot spots. The safest route had one more crossing guard and intersection. There were nineteen intersections and three crossing guards in the safest route. In the shortest route, students would pass through eighteen intersections and two crossing guards. Although this route had more intersections than routes 7, 8, and 9, the scaled costs of each intersection was not enough to divert the route (Figure 13).

Figure 13 Wolf Canyon Route 10

4.3 Conclusion

Results from both school zones lead to other findings and suggestions for model improvement as will be discussed in the next chapter. Overall, the results suggest that the network analyses produce reasonable routes that are close enough to the shortest distance while avoiding major barriers. Some results came as expected while others were unexpected, such as the cost weighted routes in Wolf Canyon being less than the shortest distance route. These findings will be discussed further in the concluding chapter.

Chapter 5 Conclusion

GIS can be extremely helpful when used as a tool in Safe Routes to School programs. In particular, Esri's Network Analyst tool provides school districts with an efficient means of modeling, visualizing, and managing walking routes in each school's service area. Although potentially useful for school districts, at this point, a staff GIS analyst or consultant will be necessary to customize models for individual study areas.

Simplifying a complex process into a two-dimensional visualization naturally comes with its own limitations. These limitations suggest areas for further development of data and routing algorithms to meet the needs of the various study areas and potential for widespread use in Safe Routes to School programs. The following sections will explore these limitations and provide suggestions for future study.

5.1 Limitations

The mapping of the safest routes to school in this study had its successes; yet, there were also some points that can be improved for various reasons. These limitations came in the form of necessity for the best data to represent the study area, selecting the most appropriate scale for analyses, and changes to land use patterns with on-going build-out at Wolf Canyon and planned redevelopment at Harborside.

5.1.1. *Data Limitations*

Having data closely fit to purpose is often a struggle within the field of GIS. Data collection is an expensive process, so often we are working with what's available and acceptable, and then considering the implications of the data used.

The model attempts to include common variables throughout multiple study areas; however, one cannot neglect certain features that are important to a particular study area. One such limitation came in the form of the crime data. The crime data from the most recent years was not available; the local governmental agency did not finalize the data until a couple of years later. Crime data may contain incidents that are under-reported (e.g. sexual assaults). Also, there often are complications with positional accuracy of crime data when it comes in from the field. To help alleviate these complications, a larger time frame was used to cover the crime within the area. The larger timeline produced the minimum number events necessary for the hotspot analyses. Although using the larger timeline was effective in building the model, precision in understanding recent changes in crime patterns is lost. Local governments often deploy policing resources to proactively address crime in challenged areas. The environment is ever-evolving; thus, the most updated data could be useful in modeling crime phenomena. This might require a school district to interface with GIS or command staff in local policing agencies.

Another data limitation was not having the students' addresses available. For privacy concerns and the protection of the student, the school district will not release this kind of information to the public. To accommodate, the model used a sample of residential parcels in place of student addresses. This demonstrates how a Safe Routes to School web application could work if students or parents entered their addresses. However, it would be within the school district's best interest to analyze routes in each school's service area to improve route safety overall. Knowing actual students' addresses may help the school district geographically weight routes in their service area, so that they can place more resources such as crossing guards or other sorts of volunteer safety programs in areas that would have greater effect in ameliorating the hazards.

Different school zones may have various features that will need to be modeled with data collected from on-the-ground observation. In the Wolf Canyon study area, this manifested as the park walkway which supported the students in their route to school. In Harborside, there was a railroad that becomes a possible danger to the students. This was omitted from the model, because most of the railroad was fenced off to students, and the point where students will cross the railroad was heavily signalized with crossing guards as discovered through on-the-ground observation. However, instances such as these cannot be ignored when replicating this model in other school zones. On-ground features within one area can vary immensely from another area. There is a need in using GIS for Safe Routes to School programs to use on-the-ground observation to supplement existing local datasets in cases these and others.

Overall, the data used made it possible to map out safe routes to school, but some areas can be looked at with skepticism. Therefore, it is necessary to look for improvements in the data whenever possible.

5.1.2. *Scale Limitations*

Scale was another major limitation within this study. This came in the form of the scale of analyses within the study area as well as scaling the costs within the algorithms.

There is accuracy within where the GIS found hotspots within each school zone. Within Harborside, hotspots were revealed in front of the school, around the shopping center, and surrounding park. In the Wolf Canyon school zone, a hotspot was produced in front of a school zone. These are all areas where crime would typically be reported. On the other hand, the Wolf Canyon school zone is anecdotally perceived as safer as a whole; families may not see traveling across these areas as a great risk. The hotspot analyses were scale-dependent. In this case, the hotspots were produced in each school zone. If the analysis was run at the district level, hotspot areas within the Wolf Canyon school zone might not be output as significant. This analysis can be further developed by parsing out the types of crime. For example, auto theft may be more likely in more affluent areas. These crimes do not affect children, so they can be omitted from the analysis. Determining the correct scale requires an on-the-ground knowledge and survey from a GIS analyst. An analyst may further review the work of Bejleri et al. (2011) to see how district-level analyses can further be integrated into the model.

Further, the polygons produced from the hotspots were quite large and this could have greatly affected the model. The algorithm that Network Analyst uses produces an added cost for point barriers based on the amount specified as an attribute property value. For line and polygon barriers, the road network distance that traverses the barrier is multiplied by the specified impedance value. If the edge is only partially covered, the algorithm apportions and then multiplies the scaled cost. Therefore, having larger polygon areas could produce greater impedance. This may be alleviated by performing district-level analyses as mentioned because the optimized hot spot analysis may produce a smaller raster grid due to the more data and increase significance of localized hot spots. Another approach would be simply reducing the costs within the algorithm for a given school service area for variables with relatively large polygon barriers.

As mentioned earlier, the Wolf Canyon study area was larger than the Harborside study area and it came with fewer barriers. This resulted in cost-weighted route lengths that were less than the shortest route length in areas where students were not routed through crime hotspots and took the supporting park walkway. To account for the added travel distance, the added cost of the point barriers could have been weighted higher within the Wolf Canyon area so that students can avoid crossing intersections as often. More study may be necessary on how the scale of the school zone affects the weighting of the algorithm. What is appropriate in a dense, compact area is not necessarily appropriate in a large, sparsely populated area. The algorithm should account more for scale.

5.1.3. *Land Development*

Lastly, the model was built using past and present data; therefore, it does not account for any future changes that will occur within the study area. The Wolf Canyon study area was unique in that it overlaps polygonal boundaries with the next nearest school, the Veterans Elementary school zone. This was a result of Veterans Elementary already being at or near capacity when the surrounding neighborhood was built. Wolf Canyon was assigned for families in the surrounding Veterans Elementary area as an overflow school. The school district at this point is in the process of building another school to accommodate the growing population in Chula Vista as a result of all of the land development. This is where partnership with the City of Chula Vista would be helpful for a GIS analyst. These models require timely data; therefore, having a source of accurate information and greater understanding of the underlying processes at play which may affect the model later is important. An application of this tool requires ongoing development, which would be the responsibility of a Safe Routes to School program leader and an associated GIS analysts.

5.2 Suggestions for Future Work

As with all studies, solving one question will lead to several more questions. Although we see how GIS can be a powerful tool when used in modeling safe routes to school, more work and future development can lead to greater function and benefit for families. Therefore, building a web GIS and walkabout study survey are suggested.

First, web GIS may be an effective means for families to use this tool. A parent could input their address and school into a website form and the output would be a map of the safest route their child can take to school. Network Analyst is not accessible to most families; it would be unmanageable for the school district to provide individual maps to each family using the methods described. However, a web GIS may be built using the concepts described in earlier chapters. A web GIS was the intention for the data model built by Huang and Hawley (2009); this research may be used to expand on that knowledge. New developments in automation may also help with the development of the web GIS. In recent years, Python programming has become better integrated with ArcGIS. This may make programming a web GIS less of a challenge. For instance, an automated script will allow for the easy manipulation of data before being placed into Network Analyst. Currently, a user needs to perform the tedious task of extracting data into individual components for scoring.

Second, as mentioned in the previous sections, the data came with its own limitations. To help resolve some of these data issues, walkabout surveys are suggested in each study area. The federal Safe Routes to School Partnership provides templates for walkabout surveys (Safe Routes to School National Partnership 2017). These can be accomplished by using parent and student volunteers. The walkabout surveys help the school district to point out areas of concern that are not apparent within the data. Parent’s perception and their decisions are very important to consider in SRTS programs. GIS is not strong in regards to qualitative aspects unless such data is gathered. This survey data can help provide more insight and establish more rapport with parents. With walkabout survey data, a GIS analyst may further customize the model to fit the needs of each individual school and better inform parents about the walking environment.

5.3 Overall Conclusions

Network Analyst is a potentially useful tool in finding safe routes to school. Like all tools, limitations come with the data that is being processed and how the tool is customized to best serve the school zone. School districts are not always working with the most updated data, and they are working with a complex and constantly changing environment. A human element and understanding of the service area is necessary in order to maintain how these tools serve the school district population. With enough maintenance, Network Analyst can help large numbers of students walk to school safely.

Safe Routes to School programs can be supported by a GIS, but a GIS cannot replace all off the components of an SRTS program. There is a potential for GIS to be a tool to help resolve some of the reasons that prevent students walking to school such as crime, traffic, and other barriers by routing around these barriers, but they do not solve why these barriers exist to begin with and the underlying causes. These programs require coordination and efforts from schools, parents, students, local government, law enforcement, and community agencies. A GIS analyst may be essential for the ongoing development of such pedestrian-friendly designs and routing tools.

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