University of Redlands

**Creating a Vibrant Place for the City of Redlands
Assessing the Suitability of an Abandoned Downtown Space for Mixed
Use Development**

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

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August 2013

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August 2013

Acknowledgements

﴿وَقُلْ اَعْمَلُوا فَسَيَرَى اللّٰهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ﴾

Foremost, completing my master's degree is probably the most challenging activity of my life. The best and worst moments of my master's journey have been shared with many people. It has been a great privilege to spend really great time in the Department of MS GIS Program at University of Redlands, and its members will always remain dear to me.

I would like to express the deepest appreciation and thanks to my comity chair, Professor Fang Ren for the continuous support of my master's Thesis, for her patience, motivation, enthusiasm, and immense knowledge.

Besides my advisor, I would like to thank the rest of my thesis committees: Prof. Douglas M, Flewelling, Prof. Russell Weaver for leading me working on exciting project. Thanks for all the faculties Prof. Mark, Prof. Ma and the nicest program coordinator Debra Riley for making everything convenient.

A big thank to my parents. Their love provided my inspiration and was my driving force. I owe them everything and wish I could show them just how much I love and appreciate them. My sisters and brothers love and encouragement allowed me to finish this journey. They already have my heart so I will just give them a heartfelt "thanks". Finally, I would like to dedicate this work to my parents and the whole family who always pray for me to reach the peak point. I hope that this work makes you proud.

Abstract

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With expanding urban population and growing need for various services, city governments and local organizations are looking for effective uses of city spaces. The City of Redlands wants to improve their use of vacant locations and provide better services to the local residents. In particular, the City of Redlands wants to apply mixed land use on the old Redlands Mall location that has been closed down. A comparative suitability analysis is conducted in a GIS to the site and surrounding areas to provide evidence to the client and the decision makers. Various factors, including schools, libraries, parks, hospitals, population density, and crime rate, are taken into consideration. The analysis results have a significant policy implication for the City of Redlands.

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List of Acronyms and Definitions

GIS	Geographic Information Systems
SGD	Smart Growth Development
TOD	Transit Oriented Development
BRA	Brownfield Redevelopment Authority
MCSDSS	Multi Criteria Spatial Decision Support System
LRT	Light Rail Transit
WLC	Weighted Linear Combination
MCDA	Multi Criteria Decision Analysis
OWA	Ordered Weighted Average
MCA	Multi Criteria Evaluation
BAO	Business Analyst Online
MSGIS	Master of Science in Geographic Information Systems

Chapter 1 – Introduction

In recent years, cities in the United States have been suffering from a rising number of brownfields. One of the biggest challenges facing urban planners and designers is to decide on the most appropriate use for abandoned areas. Most brownfields have the potential to provide benefits to the community once redeveloped effectively.

Brownfield is a term used to define a property that previously had been used for industrial or commercial land use purposes but became abandoned or derelict (Thomas, 2002). Places become abandoned for either functional or environmental reasons. Functional reasons include uselessness, lack of sufficient services, minimal parking, poor quality of service, and difficulties with accessibility. Environmental reasons include noise pollution, odor, gases, heat and dust. All of these reasons can contribute to a place becoming derelict. In the United States, “there are over 430,000 brownfields nationwide” (Thomas, 2002, p. 8). These abandoned areas lead to a rise in crimes and deterioration in urban areas. This problem is also spreading in many cities throughout the world. Because of growing needs, governments and local organizations are looking for effective uses of abandoned city spaces.

Redevelopment of a brownfield often involves land use change. In recent years, case studies from many cities have also shown that mixed land uses for residential-commercial purposes can bring several benefits, including decreasing the use of motor vehicles, encouraging walking, increasing bicycle use, promoting economic growth, and reviving urban areas (Cervero, 1996). Redevelopment of a brownfield is considered to be successful if the space’s new land use is appropriate for the surrounding area. Therefore, decisions regarding land use changes need to meet the land capability and population growth requirements. Decisions regarding brownfield redevelopment should be based on urban planning and design principles. City planners must take user requirements and stakeholder views into consideration when planning a brownfield redevelopment. Also, it is necessary to find out the land capabilities, and if the land can support residential and commercial use, as well as proximity to existing services.

The Redlands Mall, a building that was formerly used for commercial purposes in downtown Redlands, CA, is now considered to be a brownfield by city planners (Figure 1-1). The Redlands Mall was built and opened in 1977 and operated until 2007, when the owner was forced to close it for economic reasons. It remains closed to this day. The city government plans to run a redevelopment program to convert the lower section of the mall into shops, while turning the upper part into residential units. The latter of these requires an amendment to the existing municipal zoning regulations for the downtown area. However, given the mixed-use nature of the proposed project, it is necessary to produce strong evidence that shows mixed uses are appropriate for this section of the city. Therefore, this project focused on analyzing suitability of the old Redlands Mall for mixed land use. To evaluate the suitability of Redlands Mall for the mixed land use, it was necessary to perform spatial analysis. Analysis results showed whether Redlands Mall falls within those areas with the highest suitability levels. A geographic information system (GIS) was used for its strength in spatial data

management and spatial analyses. The final evaluation results can aid decision-makers in the City of Redlands with deciding the best potential use for Redlands Mall (Figure 1-1).

Figure 1-1. Redlands Location.

1.1 Client

The client for this project is the City of Redlands, and the point of contact is Tom Resh, the GIS administrator for the city. Redlands has a GIS department that works with Esri and the University of Redlands to develop and deliver geographic information to the public and city employees of Redlands (<http://www.cityofredlands.org/GIS>). The client provided the data required to complete this project, which includes buildings, land use, services, streets, demographics, and the information about the Redlands Mall (history, general characteristics of the building). The GIS department is willing to help, orient, and support involved parties throughout the lifecycle of the project.

1.2 Problem Statement

The Redlands Mall, a building located in Downtown Redlands, has been abandoned since 2007. This abandoned building has turned into an unsafe place. Redlands Mall poses a crime risk to the city (Figure 1-2). Moreover, keeping a building abandoned will damage the image of historical downtown. The city government has decided to run a program of redevelopment for the abandoned mall. This change entails modifying the land use zoning in the downtown area of the city. City planners have decided that a mixed-land use zoning that allows for commercial and residential land use is preferred for the proposed redevelopment plan. However, the city needs evidence to support the proposed plan.

Figure 1-2. Crime Rate (Sq.-mile).

1.3 Proposed Solution

The proposed solution is to perform a suitability analysis that can provide the necessary evidence to evaluate the recommended redevelopment plans for Redlands Mall. The suitability analysis was designed to enable users to analyze spatial patterns of different variables, such as proximity to stores and roads, and effectively display results with GIS technology (Malczewski, 2004). Various characteristics of a site such as proximity to schools, hospitals and shopping centers that influence the suitability were considered (Jain & Subbaiah, 2007).

1.3.1 Goals and Objectives

The main goal of the project was to critically evaluate the redevelopment proposal for Redlands Mall. Specifically, the project examines the capacity of the Redlands Mall site to support mixed land uses, based on a number of criteria. The results of this analysis will assist the city and all decision makers in weighing the advantages and disadvantages of the proposed redevelopment plan.

1.3.2 Scope

Two aspects need to be defined in this project: the study area and the GIS technique. In this section, the scope of the project will be defined in detail.

The study area is Redlands Mall, so this project will concentrate on the downtown area. The downtown area of Redlands is a vital zone for the city in terms of economy,

history, and culture. For this project, ArcGIS Spatial Analyst is used to create a tool and generate maps that assign suitability to sites based on distances, services and accessibility.

The client was responsible for providing the required data and overseeing the process. In addition, the client has evaluated and provided feedback to help correct and improve the workflow. The responsibilities were to meet the client requirements and accomplish the objectives of the project on time.

1.3.3 Methods

In this project, a land use suitability analysis was necessary to ascertain whether the location of Redlands Mall has the potential to support both residential and commercial uses. After reviewing literature on some similar projects and contacting the client, criteria for this project were determined. Those criteria were based on basic needs for applying integrating residential land use into existing commercial land uses.

Distances to facilities are the most important factor in the suitability analysis. In this case, the criteria were defined based on proximity to services, such as schools, hospitals, and shopping centers. Each facility was given a maximum distance (e.g. schools ≤ 0.5 mile) that represents the coverage of its service area. Locations closest to the facilities were scored highest. Additionally, density of traffic accidents and crime were considered as important aspects in the suitability analysis. Areas with the highest concentration of crimes and traffic accidents were scored the lowest. The main objective is to score the level of suitability across the entire city. The tool used is “Fuzzy Membership” which assigns a value that ranges from 0 to 1 for each location in the city of the output raster. These values indicate the probability of being a ‘member’ of the suitable areas. Values closer to zero represent the lower suitability areas and values closer to 1 represent areas with higher suitability. In the case of the facilities (e.g. schools), the Fuzzy Membership tool will assign higher membership values to areas closest to the defined criteria. As distance increases from each facility, the membership value will decrease gradually.

1.4 Audience

Most of the people who will use the end products are familiar with the technical vocabulary used in GIS. The audience for this project is the GIS department in the city of Redlands (City Hall). However, the results of this project are useful for other audiences; for example, local stakeholders and urban planners.

1.5 Overview of the Rest of this Report

The first chapter covers the general information about the project: client, the problem statement, the proposed solution, the main goals and objectives, scope, methods, and the audience that is addressed.

In the second chapter there is a comprehensive literature review which expands upon brownfield redevelopment as well as the application of mixed land use in urban areas. The third chapter is titled “Systems Analysis and Design” and contains the requirements analysis, system design and project plan.

Chapter 4 focuses on the description of the database design in terms of the conceptual and logical model. Data sources, methods for data collection and data scrubbing, and loading are discussed in chapter four as well.

The fifth chapter concentrates on detailed description of every step that the project has been through, including the technique and ArcMap regarding the analysis of the data.

Chapter 6 shows the results of the analysis and how can be useful for the client. Additionally, the results of the analysis will show the zero ignorance and the knowledge obtained through this program.

In the last chapter, the complete project process is summarized and areas of future work are discussed.

Chapter 2 – Background and Literature Review

Geographic Information Systems (GIS) has increasingly found prominence in geospatial studies, planning, and management. For example, GIS can be used for planning development initiatives such as identification of lands suitable for various agricultural activities, development of factories and infrastructure such as roads and railways lines. GIS may also be used by conservationists to identify threatened ecosystems which need to be protected from harmful anthropogenic activities, or by emergency planners to determine the most appropriate routes that can be used during rescue operations. Most relevant to this project, GIS is available tool for identifying and resolving conflicts that may arise from land use.

Since the origin of GIS, it has been applied in suitability analyses because it allows storing, analyzing, displaying, and overlaying various spatial and non-spatial data. To do so, GIS has greatly enhanced the planners' capacity to make decisions on matters that involve land allocations and management of the environment. The applicability of GIS in suitability analyses is vast, and new methods of spatial analysis facilitate suitability assessment and land use allocation (Collins, Steiner, & Rushman, 2001). Today, most suitability analyses are performed using GIS techniques to combine different factors to obtain the results that meet the requirements.

2.1 Brownfield Redevelopment

'Brownfield' is a term used to define a property that previously had an industrial or commercial land use and but became abandoned or derelict (Thomas, 2002). Since brownfields represent a major issue in many U.S. cities, they are widely discussed in the urban planning literature. Most practitioners argue that decisions made about brownfield redevelopment should be based on urban planning and design principles. However, quick growth and sprawl bring new needs and demands for planners and designers, including the consideration of new growth and new alternatives for land use (Brueckner, 2000). Every decision must be assessed and supported. GIS is one of the many ways to help with decision making.

Several studies have discussed the convenience of using GIS to identify and determine the best future uses of brownfield areas. For example, Boott, Haklay, Heppell and Morley (2001) applied GIS to redevelop abandoned urban sites in Wandle Valley, South London. The growing population in South London, United Kingdom has increased housing demands, which forced the government to develop a sustainable strategy that included brownfield redevelopment as a solution. The first step of the project was the identification of the important stakeholders to define the users' requirements, and clarify the difficulties that the developers and planners faced while dealing with brownfield sites. Collecting data about the communities proved difficult, because the data came from different sources and in different formats. After collecting data, sensitive areas were identified that could influence the brownfield sites. Different criteria were used to determine the most appropriate brownfield sites for housing, for example the proximity to green areas (over 400 meters), shopping centers (within 1 kilometer) and underground stations (service area of 1 kilometer), as well as flood risk areas. Data overlay analysis

was performed in GIS to identify which brownfield sites met the criteria. In their results, they identified sites where they would implement the brownfield solution. The results were presented to the stakeholders through a workshop and GIS was proved to be a valuable tool for planners and the public to make decisions in urban areas (Boott, Haklay, Heppell, & Morley, 2001).

According to Meyers (2010), GIS can also be used to evaluate to plan for Smart Growth Developments (SGDs) and Transit Oriented Developments (TODs). SGDs concern expansion strategies that are financially smart and environmentally friendly, and combine appropriate planning of mixed land uses development. TODs focus on revitalization of marginalized areas through availing cheap and readily available modes of transport such as light railway lines. This eases the ability of individuals from marginalized areas to commute to towns and also makes investment in structural developments in the marginalized areas more sustainable. It is noted that land use and transit connections can be vital in the revitalization of neighborhoods, as they play an important role in lowering poverty levels and lowering crime rates among communities. Through the application of GIS, models which aptly reflect the tendencies of particular areas to sustain intensive Smart Growth Development and sustained Transit Oriented Developments can be created.

In 2002, the state of Michigan realized a need to redevelop brownfields located in Jackson County, which consist of 19 townships and is geographically isolated from other cities in Michigan. In the 1970s and 1980s the region suffered from decay in economic and population growth. The Brownfield Redevelopment Authority (BRA) designated candidate sites to be redeveloped. In this project, a GIS-based decision support system was created for the brownfield areas in Jackson County. The decision support system integrated three elements: (1) a technique to access data through web-based tools, (2) a suitability tool to analyze the data based on pre-defined criteria using Smart Places, and (3) a GIS-based land use modeling application to support the analysis. The criteria used were weighted based on their relative importance through point values—for example, industrial areas were assigned with a value range of 120 to 220, commercial between 140 and 200, residential between 90 and 120 and agricultural/open space fall within 70 and 120.

The decision support system provided access to spatial information regarding land capability, development incentives, public goals, interests, and preferences. Using those methods in conjunction with environmental sites assessment, they identified and ranked the brownfield areas for redevelopment. Additionally, the decision team identified alternative sites using the Smart Places GIS (Thomas, 2002).

2.2 Land Use Suitability

To redevelop a brownfield site, it is critical to determine the appropriate land use for that location. As such, land suitability analysis is often required in land development projects. The Land suitability is defined as the appropriateness of a given for specific uses (Food and Agriculture Organization of the United Nations, 1976). Suitability analysis enables finding the most suitable land uses for a site based on predefined criteria. In general, suitability assessment aims to help decision makers, such as environmental managers and planners, ascertain optimal results regarding land zoning, services, transportation, etc. Decisions regarding land uses must consider three factors: location, development actions,

and environmental elements (Collins, Steiner, & Rushman, 2001). There are two types of suitability assessment: qualitative, which evaluates land capabilities and produces results in qualitative terms such as high suitability or low suitability; and quantitative, which produces numerical results and permits a wide range of statistical analysis (Dent & Young, 1981; Baja, Chapman, & Dragonvich, 2002). In most cases, these two approaches are integrated into a single suitability analysis.

Suitability analysis using GIS can also be used to help identify regions in which conflicts between communities are likely to occur (Carr & Zwick, 2005). In this case, a landscape is categorized into four sets, namely, productive areas where human inputs in maintaining high productivity levels inhibit succession, protective areas in which progression is allowed to progress into maturity, and compromise areas in which the protective and progressive areas are combined and urban or industrial areas. In their study, Carr & Zwick (2005) classified the suitability of a tract of land for a particular land use from 1 to 9, where 1 indicates the lowest suitability and 9 the highest suitability.

Through the application of computer simulations, the areas of these four categories can be manipulated to objectively determine the limits of each part that is necessary in order to preserve regional balances while ensuring that important materials can still be obtained from these areas. In this example, GIS was applied to improve regional planning by recognizing probable areas of upcoming land use conflict.

To accomplish a purposeful assessment of the land suitability, it is necessary to include different criteria for which factors are currently influencing the land use. To consider multiple factors in one analysis, multi-criteria evaluation (MCE) is often used. MCE usually employs two procedures, namely the Boolean overlay method that applies non-compensatory combination rules, and the weighted linear combination (WLC) method which that applies the compensatory combination rules. In WLC, each factor has a different level of importance in the suitability of a land, and this is expressed through weights (Baja, Chapman, & Dragonvich, 2002; Dent & Young, 1981). The Boolean overlay method focuses on the thresholds of suitability for all criteria assessed in order to produce Boolean maps. These maps are then combined together by applications of logical operators including unions (OR) and intersections (AND). The weighted linear combination method standardizes factors into common numeric ranges, which are later aggregated by weighted averaging. The two procedures can be used in the structure of the ordered weighted averaging (OWA) where qualitative statements are used as fuzzy quantifiers.

One of the challenges associated with MCE approach is that the two specific methods tend to yield different results despite expectations for them not to do so (Jiang & Eastman, 2000). For instance, while using the Boolean overlay method, the Boolean intersection operator results into some regions being omitted from the results whenever the WLC method uses the tradeoff or substitutability feature to compensate for low and high scores among various criteria. Another problem associated with MCE involves the issue of standardizing factors within the WLC where the approach of rescaling ranges to a single numerical basis has never been justified.

GIS can be used to serve the purpose of MCE for suitability assessments and offer the characteristic values for various locations (Miller, Collins, Steiner, & Cook, 1998; Mokerram & Aminzadeh, 2000; Malczewski, Chapman, Flegel, Walters, Shrubsole, & Healy, 2003; Sakellariou, Katsios, & Magafosis, 2006). One example of land suitability

analysis using GIS took place in Prescott Valley, AZ, where the suitability of potential sites for greenway development needed to be identified (Miller, Collins, Steiner, & Cook, 1998). The process of analysis consisted of five steps: identification of land functions, collection of data, identification of priorities (weighting values), data analysis in GIS (combining and overlaying), and evaluation of results. After identifying analysis process, three functions were determined: wildlife habitat, recreation and riparian corridor. Each one of these functions had four factors which were rated based on land capability, and assigned a value for each factor (high, moderated, low, and no capability). Expert opinion was used to determine the importance of each function. The resulting map showed large areas unsuitable for greenway development. The model showed its capability of integrating physical, environmental and social geographic data with people knowledge. Also allows using different information to be weighted.

Another example was discussed in Sakellariou et al. (2006), where a multi-criteria spatial decision support system (MCDSS) was created to find the most suitable areas for industrial use in the northeast coast of Peloponnese to address region's the need for sustainable. Various criteria were selected based on literature, empirical studies, and stakeholders' opinions. Subsequently, the criteria selected were ranked with different values to indicate the importance of each criterion and then were processed and overlaid in GIS. In addition, they performed a sensitivity analysis on the selected criteria and final map was created showing higher suitability score areas as the most appropriate for industrial use.

In the context of suitability analysis, it is evident that the connection amidst the prominent land use as well as the transit choices including building *Light Rail Transit* (LRT) can be harnessed to invigorate neighborhoods, discontinue poverty cycles and minimize crime rates. GIS, as a powerful tool, can be utilized to systematize, sort, analyze spatial data, and establish models that depict an area's susceptibility to sustain TODs & SDGs (Meyers, 2010).

Metropolitan authorities continue to realize the importance of SGD and TOD in evaluating the attachment of land users and transit routes in addressing the problems related to unplanned developments such as inappropriate housing projects and construction of public amenities among others. Through building the automated workflow in GIS, areas appropriate for SGD and TOD can be easily identified (Meyers, 2010). The automated workflows can be used repeatedly for different scenarios when parameters are changed. The ModelBuilder application in ArcGIS is a popular platform to build the automated workflow. The mentioned provisions demonstrate how GIS can be applied in the suitability analysis in various contexts.

2.3 Suitability Analysis Using Fuzzy Logic

Although MCE is very helpful in suitability analysis, it involves the risks of making incorrect decisions. For example the weighted linear combination normalizes factors in expression of the perspectives of suitability for various locations. The lower the standardized score for a location or piece of land, the less suitable it is for its intended use. The threshold which may be used to conclusively determine the best locations is not available and this results in various uncertainties. Such uncertainties are adequately addressed through application of the Fuzzy measures and through taking decision making to be a set problem (Jiang & Eastman, 2000). For the Boolean overlay method, crisp

boundaries between classes make it hard to accommodate the vagueness naturally involved in semantics. The Fuzzy measures offer strong logics during the course of standardization and are important in bridging the gaps between Boolean assessments and weighted linear combinations (Mokerram & Aminzadeh, 2000). Contrary to Boolean logic, Fuzzy logic determines a degree of membership that falls into a range of values from 0 to 1, which avoids crisp boundaries (Collins, Steiner, & Rushman, 2001). Since this approach is completely flexible in terms of determining the membership of elements in a set it has been employed into suitability analysis (Jiang & Eastman, 2000; Joerin, Thériault, & Musi, 2001).

Joerin et al. (2001) developed a decision support method for land suitability assessment (MAGISTER) through the combination of GIS and multi criteria decision analysis (MCDA) to evaluate housing suitability in a rural area in Switzerland. Fuzzy logic was applied to construct a partial suitability index for each criterion with values ranging from 0 to 1, and the membership function associated with favorable conditions. For example, noise level was measured through proximity to roads and rails and then applied a Fuzzy Membership function to it. This criterion was integrated to the rest in order to obtain the general suitability results for housing.

Finally, MCDA was used to integrate these partial suitability maps in a holistic suitability index using a method called ELECTRE-TRI. Since this method is not capable of processing every cell in the study area, a homogeneity index was calculated to group cells in homogeneous zones. The ELECTRE-TRI method compared each zone with other reference zones. After these comparisons, the resulting map showed every zone classified as favorable, unfavorable, or doubtful.

In another example, Jiang & Eastman (2000) discussed and applied the aggregation operator Ordered Weighted Average (OWA) as an approach providing continuous fuzzy aggregation between fuzzy intersection (AND) and union (OR) in a case study in Kenya. A fuzzy sigmoid-shaped function was used in both Boolean overlay as well as weighted linear combination using a fuzzy sigmoid-shaped function to standardize each factor under consideration. Then, the factors were aggregated using different OWA approaches which yields significantly different results. The aim of showing different results is to allow the decision makers to choose the appropriate “AND – ness” and “OR - ness” of the area.

2.4 Summary

Suitability analysis enables finding the most suitable land uses for a site based on given criteria. Suitability assessment aims to help planners and public officials make evidence-based decisions regarding land zoning, services, transportation, etc. To accomplish a purposeful assessment of the land suitability, it is necessary to include different criteria for which factors are currently influencing the land use. GIS can be used to serve the purpose of multi-criteria evaluation for suitability assessments and offer the characteristic values for various locations. In this project, multi-criteria decision analysis was applied to have a gradient of suitability considering different factors. One of the methods used was the fuzzy logic as it shows suitability through continuous values avoiding crisp limits between suitable and not suitable areas. The suitability analysis was used to create a tool that allows the user to view, edit and update the inputs as well as the criteria and use the results to support decision making.

Chapter 3 – Systems Analysis and Design

This chapter depicts the process of project planning and design. In this chapter, the problem that is intended to be solved will be addressed in section 3.1, as well as functional and non-functional requirements of the analyses in section 3.2. The system design in section 3.3 defines the major components and how they fit together. The last section of this chapter, section 3.4, addresses the initial project plan and the changes and updates that have been applied to the current project plan.

3.1 Problem Statement

The Redlands Mall, a building located in downtown Redlands, California, has been abandoned since 2007. Since then, crime rates around the building have increased dramatically and sparked a disturbance in the urban image of surrounding areas. There is a major concern of these issues and the consequences to the community, which has led The City of Redlands to try to find an appropriate solution. The current plan is to run a redevelopment program to revitalize the abandoned mall and the surrounding community.

Due to the important location of the mall, the City of Redlands has decided to redevelop this building as a mixed land use, with residential on the top floors and commercial in the bottom floors of the mall. Since downtown Redlands is zoned as a commercial area, the proposed changes to the mall would entail a change in the zoning regulations of the entire downtown area. To ensure future success of the mixed land use proposal, the City of Redlands requires evidence that the proposed changes to zoning will provide lasting benefits to the community.

3.2 Requirements Analysis

This project had several requirements based on client requests which were met through several suitability maps as well as a tool. These products were designed to assist the city's decision makers in taking steps forward regarding land use issues. This section addresses what was taken into consideration to accomplish the results and meet the client requirements. Every requirement was categorized as functional or non-functional.

3.2.1 Functional Requirements

Functional requirements refer to the main components required to apply a suitability analysis on the client's data. As listed in Table 3-1, the first functional requirement was to build a geodatabase that permits the manipulation, accessing and storage of relevant data in an organized way. The geodatabase shall be divided in several dataset categories based on predefined criteria.

Data analysis is the most important requirement and consists in a series of steps that lead to the calculation of suitability for mixed land use. Since the suitability is mainly based on proximity to services, the first phase of data analysis is the calculation of distances. The system should be capable of considering multiple criteria and overlaying these criteria in ways that meaningfully describe the suitability of the Redlands Mall for mixed-use development.

Another requirement is the creation of a tool that will allow the user to perform the suitability analysis independently. The functionality of the tool can be extended to include other criteria and cost factors.

The required outputs of the project are the previously mentioned tool as well as a suitability map. This final map displays results of suitability analysis for the whole city including Redlands Mall location. This will allow deciding whether Redlands mall is an apt place to apply mixed land use.

Table 3-1. Functional Requirements

Requirement	Description
Geodatabase	Construction of geodatabase shall allow easy access to querying, storage, and manipulation.
Data analysis	Analyzing the data shall calculate suitability values for the whole city based on multiple criteria
Tool	The tool shall gather all steps of analysis and through an interface allow the client and other users input different depending on their objectives.
Outputs	The outputs shall provide a tool and maps showing the results.

3.2.2 Non-Functional Requirements

Non-functional requirements include several aspects on how the system works. First of all, the tool was created using ModelBuilder in ArcGIS Desktop 10.1. In order to run the tool, the user must have access to this software and be able to input its own data on it.

The tool created is flexible for the user to input different data as well as different criteria. This requirement consists of allowing the user to apply the tool not only for Redlands city, but for any other city. Also, the tool is capable to function with different criteria depending on the needs of the user and the specific project.

The interface is easy to understand and operate for the client of this project as well as other users. The creation of a user friendly interface is a very important requirement, because it determines the appropriate use of the tool as well as the accurateness of its results.

The clear visualization of results allows the decision makers to distinguish the highest and lowest suitable areas in the city of Redlands. Considering that some decision makers are not very familiar with GIS display of data, it is very important that final maps communicate appropriately and clearly the intended message (Table 3-2).

Table 3-2. Non-Functional Requirements

Requirement	Description
ArcGIS Desktop 10.1	The tool was created using ModelBuilder in ArcGIS Desktop 10.1.
Tool flexibility to input different criteria	The tool shall be flexible to work with different data and criteria depending on user's needs.
User friendly interface	The tool interface shall allow the client and other users such as urban planners to have easy access for understanding and operating the tool.
Clear visualization of results	The visualization of results shall allow the user to distinguish highest and lowest suitability areas in reference to its value from 0 to 1.

3.3 System Design

The suitability model can be used by city planners to aid in decision making regarding changes in zoning. The user must understand how to use this model and how to interpret the outputs. The results of this model will show the level of suitability for the entire City of Redlands ranging from the most to the least suitable areas. The location of interest will be examined and measured based on the suitability of the area according to the defined criteria.

The system design of the suitability model was created for decision makers within the City of Redlands. It includes four main components: user, inputs, data analysis and outputs. The first and one of the most significant elements of the system is the user. In this project, the end user is the City of Redlands, which is also the client. As shown in the diagram, the user provided all required data and assisted in the criteria design based on City of Redlands regulations. Data and criteria are the system inputs, necessary to perform the analysis.

The arrangement of the data provided was not appropriate for the project, thus it was necessary to reorganize it into a proper format for the model. Selection, extraction and rearrangement of data were carried out prior to loading data into the model.

The suitability analysis is the most important element of the system and includes three main stages. The first stage is the calculation of cost distances to facilities, amenities, services, safety, and transportation. Distance calculations are based on a cost surface, which reveals all those paths in the city that are relatively easy to traverse.

Cost distances are necessary for the next stage of data analysis, the membership calculation. Membership calculation produces values that indicate the probability of being suitable relative to a given criterion. Since membership produces one resulting map for each criterion, all maps have to be overlaid in order to achieve a multi-criteria suitability analysis. Overlay is the final stage of data analysis. The output of the analysis is one single map indicating suitability for each area in Redlands. Final suitability map will show whether Redlands Mall location falls within the most suitable areas for residential-commercial use.

The final products that will be generated should contain maps, a tool and information about level of suitability in each study area. The map will show several results of the analysis, depending on the criteria defined by the user. The tool will enable user to define his/her own suitability criteria and allow people who are not GIS professionals to do the analysis in a straightforward way. This tool aims to provide support for land use and zoning decision.

3.4 Project Plan

The final plan for this project consisted of several tasks with varying levels of priority. The first task was the acquisition of data gathered from the client and other sources. Data from the client were provided in the shape file format. This task was critical to begin the project because the data needed to be cleaned carefully prior to the analysis.

The second stage of the project was to determine the criteria which factors affect the suitability of Redlands Mall location for the intended mixed land use. These factors were primarily determined by the client, and they included proximity to facilities, amenities, services, safety, and transportation. Criteria were based on the regulations of the City of Redlands to achieve suitability analysis. This step was a high priority, as the criteria were crucial for the analysis (Table 5-1).

The third stage of the project was developing an organized geodatabase. The geodatabase was developed for the client to manage, organize, and share the data easily, as well as manipulate different data formats. Inside the geodatabase, data were organized

in different datasets according to the categories of criteria (facilities, amenities, services, safety and transportation).

The fourth task was the creation of the suitability analysis tool using the ModelBuilder application in ArcGIS. Several tools in ArcGIS were used, including Cost Distance, Euclidean Distance, Is Null, Raster Calculator, Fuzzy Membership and Fuzzy Overlay. The analysis of data was performed through suitability methods which required different procedures to produce the final results.

The next task was testing the model to verify that the tool worked appropriately. Testing consisted of running the model several times to ascertain that the results are correct and avoid any future errors. The tool creation included the design of the user interface.

Finally, the feasibility of the Redlands Mall for mixed land use was analyzed based on the suitability map produced by the suitability tool and the documentation of the project was completed.

Some modifications to the project plan were necessary because the objectives changed since the initial project plan was written. The project originally was intended to perform an analysis to nominate a new use for Redlands Mall. According to recent updates from the client, the City of Redlands has purchased the old Redlands Mall and is planning to convert it to residential-commercial. Given this change, the project objective was changed to provide evidences that support the change of zoning type from commercial to mixed land use. As a result, the suitability analysis approach was adopted to evaluate the suitability of the Redlands Mall location for the new intended mixed land use. These changes led to modifications of the general plan of the project. Although some requirements remained unchanged, others were delayed.

3.5 Summary

This project aims to provide evidence to support the decision to rezone one of the most important parts of downtown Redlands. The city government intends to apply a mixed land use which combines residential and commercial land uses.

Requirements were classified as functional or non-functional. Functional requirements included the construction of a geodatabase, Analyzing data to calculate the distances for suitability analysis, the creation of a tool and user interface, and the final products –suitability maps. Non-functional requirements were the software used ArcGIS desktop10.1, tool flexibility, and user friendly interface.

System design contains several elements that interact with each other and the most important resource of the company –people. The client and stakeholders are the users of the suitability outputs. The data needed was provided by the client but it was necessary to reorganize data into a format appropriate for use in the analysis. The new arrangement of data allows the client and stakeholders to more easily access, store and manipulate data.

The implementation of the project should yield suitability maps for decision makers within the city government to provide evidence for decisions made for the mall, and future land-use decisions. The project plan was designed and priorities of requirements were established early on the project, however it was necessary to adapt the plan to meet changing requirements.

Chapter 4 – Database Design

This chapter describes the project database design by detailing the conceptual and logical data models. The conceptual model includes the essential elements that take part in the general problem solving as well as the relationships between them. On the other hand, the logical data model included the organization of data inside geodatabase and how the data fit together. Moreover, the chapter mentions the data sources and talks about data collection methods as well as the process of organizing and cleaning data.

4.1 Conceptual Data Model

The conceptual model outlines the fundamental elements that participate in the analysis. Since the goal of the analysis was to measure the suitability of mixed land use zoning change to downtown Redlands, it was necessary to determine the relevant variables that affect the suitability of the downtown Redlands for the intended land use. After consulting with the client, five categories of variables were chosen and their impacts on mixed land use were outlined in the conceptual data model. They are safety, amenities, facilities, services and transportation.

The conceptual model was broken into six separate models for clarity. Five of them represent the relationships between each of five categories of variables and mixed land use. The last conceptual model takes all five categories of variables into consideration to evaluate whether a place is suitable for mixed land use.

Figure 4-1. UML Diagram of Safety Conceptual Model.

The safety conceptual model includes hospitals, fire stations, police stations and other health facilities. Closeness to safety facilities is essential for residential areas. Thus, areas within close proximity to safety facilities will be given a higher suitability score than other areas (Figure 4-1).

Figure 4-2. UML Diagram of Facilities Conceptual Data Model.

The facilities conceptual model includes certain elements which are also essential to residential areas: postal offices, libraries and schools (Figure 4-2). Their presence is indispensable because people often require access to them on a frequent basis; more importantly, proximity to these facilities is important for residents that do not drive, such as youth and elderly that heavily depend on the walkability of their residential areas.

Figure 4-3. UML Diagram of Amenities Conceptual Data Model.

Although certain amenities are not considered as indispensable as safety infrastructure and other facilities, recreational amenities are important factors to be included in city planning. This category contains several elements such as stadium, museums, theaters, bars, restaurants, and parks. Some of these components are more often visited for different activities, for example parks and restaurants. Thus, the distances to these amenities should ideally be short and have sidewalks. Some others, such as the stadium, are not visited as frequently, but should be within a short driving time from residential areas (Figure 4-3). Since the new intended land use is planned to be mixed of both residential and commercial, closeness to restaurants, bars, theaters and other commercial facilities would support the economic dynamics of the area.

Figure 4-4. UML Diagram of Services Conceptual Data Model.

To be classified as mixed-land use, the area has to meet government regulations that the client provided as well as fit the needs of the residents. Local government offices such as courthouses, Department of Motor Vehicles, and city hall are essential for the maintenance of the local economy and community. In addition, it is important for companies to be located within a close proximity of the city center as they provide employment and various services to the community such as shopping centers and grocery stores. Churches and other religious centers also serve the community in many ways from providing shelter to food to community growth (Figure 4-4).

Figure 4-5. UML Diagram of Transportation Conceptual Data Model.

Proximity to highways should be within a particular distance based on the instructions provided by the client (ideally within 1 mile from local roads). However, highways should not be too close (within about 984 ft. of residential areas) because it has negative consequences such as increased levels of noise and air pollutions. Easy access to public transportation is another important factor to consider when determining suitability of an area to serve a broader audience (Figure 4-5).

Figure 4-6. UML Diagram of Suitability Conceptual Data Model.

To determine the suitability for land use, all of aforementioned factors must be considered. Figure 4-6 brings the elements outlined above together into a conceptual model for determining the suitability of Redlands Mall for a mixed-land use zoning change.

4.2 Logical Data Model

The logical data model is an implementation of the conceptual model, as it specifies how the concepts are represented and stored inside the database. ArcGIS geodatabase has the capability to manage a large amount of data in both vector and raster formats. Geodatabase allows easy integration and manipulation of data for analysis and further steps in project implementation. Figure 4-7 shows overview of the geodatabase design for this project.

Figure 4-7. Feature Classes within Geodatabase.

The Suitability geodatabase consists of six datasets, each one designated for the specific category of data it contains, e.g. the Facilities dataset contains the feature classes of schools, libraries and postal offices, while the Study Area dataset includes the feature classes of the Redlands Mall, the commercial and residential areas in the city, as well as the city boundary. In addition, a standalone feature class is contained in the geodatabase, which has information about Redlands population density in 2010. This feature shows the distribution of population in the whole city which will help to define where the people prefer to live. Population density was compared to the suitability map and demonstrates how people are likely live nearby safety, services, amenities, facilities and transportation. Because the suitability analysis was performed with rasters, the vector data in the Suitability geodatabase were converted to raster format prior to the analysis. A second geodatabase was created to store the outputs from each step of the analysis. These outputs include a cost surface indicating the travel cost in the city, rasters of distances to each type of features (e.g. parks), probability of membership, and final suitability result. Since twenty factors were considered, nineteen rasters were produced to represent the distances to these features. Correspondingly, nineteen membership rasters were generated for these features. Concept of Fuzzy Membership function will be elaborated in Chapter 5.

4.3 Data Sources

The data provided by the client were stored in a geodatabase which contains two datasets: zoning and street networks. The zoning dataset contains feature classes about the city, such as census blocks with 2010 population, general plan, buildings, parcels, and vacancy. The street networks dataset includes roads, network junctions, stop signs, and traffic lights. Other data were retrieved from the shared drive of the MS GIS program at the University of Redlands. These data were including churches, parks and schools. All

data were projected in NAD_1983_StatePlane_California_V_FIPS_0405_Feet coordinate system as recommended by the client.

4.4 Data Collection Methods

Meetings with the client were set up frequently in order to determine the required data for the analysis. As mentioned before, most of the data were provided by the client and some other obtained from University of Redlands MS GIS program.

4.5 Data Scrubbing and Loading

The original data were not provided in an appropriate format for suitability analysis; therefore, extensive data reorganization, extraction, and rearrangement were required.

A new file geodatabase was developed for data storage and a second geodatabase was created for storing results from the analysis. The suitability geodatabase consists of six datasets; each dataset has several feature classes grouped according to the categories of criteria design: facilities, amenities, safety, services, and transportation. The last dataset contains feature classes regarding to the city of Redlands.

4.6 Summary

This chapter focuses on data models and database development. The conceptual data model represents the primary entities essential for the suitability analysis and their relationships. The logical data model illustrates the organization of data implemented in the geodatabase.

The main data source was the client. All data required reorganization prior to analysis. The result was two geodatabases, one for storing data, and another for storing the results that the city's planners can ultimately use to answer the question asked by the client and determine the suitability of the Redlands Mall for mixed-land use zoning.

Chapter 5 – Implementation

This chapter explains the process taken to perform the suitability analysis and tool creation. The analysis aimed to provide evidence for the client to support their decisions of changing land use zoning for the Redlands Mall.

Suitability analysis was an appropriate method to achieve the goals of this project, because it considers multiple criteria to evaluate the aptness of different areas for the intended mixed land use. The criteria design in this project was focused on proximity to different types of features such as schools, parks, restaurants. Conventionally, a predefined distance value, such as 1 mile to restaurants, or different classes of distances, were used to evaluate suitability of a location for the intended land use. The limitation of this approach lies in the discrete boundaries among different classes. To handle this problem, fuzzy logic was used in this project to consider vagueness of natural language and uncertainty in defining different classes.

Section 5.1 describes the process of defining the criteria. Section 5.2 details how the cost surface was calculated. In Section 5.3 the calculation of cost distances is explained, along with its importance for the suitability analysis. Section 5.4 describes step by step the application of fuzzy logic which was divided in two subsections: Fuzzy Membership and Fuzzy Overlay. Finally, Section 5.5 illustrates the creation of the tool in ModelBuilder application in ArcGIS as well as the design of the user interface.

5.1 Criteria Design

The criteria for this project were defined in collaboration with the client based on the city's regulations. The criteria were divided into five categories: safety, facilities, amenities, services, and transportation. Each category consists of sub-categories; e.g. hospitals, police stations and fire stations belong to the category of safety. Since suitability measures rely on proximity, acceptable distances were defined for each criterion. For example, a place is considered to be suitable for mixed land use if it locates within 3 miles from police stations. Table 5-1 lists all the distance values defined as suitable proximity for mixed land use for each criterion.

Table 5-1. Suitability Criteria and Suitable Proximity Definition.

Category	Variables	Proximity
Safety	Police stations	< 3 miles
	Fire stations	< 3 miles
	Hospitals	< 3 miles
	Other health facilities	< 2 miles
Facilities	Elementary schools	< 0.5 mile
	Other schools	< 1 mile
	Libraries	< 0.5 mile
	Postal offices	< 0.5 mile
Amenities	Stadiums	< 5 miles
	Museums	< 5 miles
	Theaters	< 0.5 mile
	Bars	< 0.5 mile
	Restaurants	< 0.5 mile
	Parks	< 0.5 mile
Services	Companies	< 5 miles
	Governments	< 5 miles
	Shopping Centers	< 0.5 mile
	Churches	< 2 miles
Transportation	Access to Highways	>984ft <1 mile
	Bus stops	< 0.5 mile

Compared to other suitability variables, access to highways placed a special constraint. Areas far away (more than 1 mile from highway entries) were considered less suitable for mixed land use, while areas too close to highways (within a 984 feet radius of the highway) were deemed unsuitable due to noise and air pollutions. As such, ideal locations for mixed land use should be located within 1 mile but more than 984 feet away from the nearest highway.

5.2 Creating Travel Cost Surface

To evaluate proximity of any location in the city to the targeted features, such as parks, the costs of traveling to these features needed to be calculated. To do that, a continuous travel cost surface was first created to represent the cost of traversing the entire city. Since people most likely drive or walk on the streets (Figure 5-1) the travel cost on the street network is the least, and it rises when the distance from the streets increases.

Figure 5-1. Redlands Roads.

The Redlands Roads feature class was first converted into raster format. Then the Euclidean Distance tool in the Spatial Analyst was used to calculate linear distances from each cell in the output raster to the nearest source - in this case the sources were Redlands roads (Figure 5-2).

Figure 5-2. Euclidean Distance to Roads (ft).

The next tool used was the Reclassify tool to convert continuous values derived from the Euclidean distance raster into three classes based on the level of difficulty to travel through those cells. Class 1 indicates the least travel cost value, from which the roads were delimited. Classes 2 and 3 defined areas outside the roads limit, which could represent areas containing or having the potential to contain buildings, houses, parks, etc. (Figure 5-3). These classes were needed to be an appropriate input for the cost distance tool. This travel cost surface utility will be explained in detail in the next section.

Reclassification

Old values	New values
0 - 100	1
100 - 1000	2
1000 - 15000	3
NoData	NoData

Classify...

Unique

Add Entry

Delete Entries

Load... Save... Reverse New Values Precision...

Figure 5-3. Reclassification of Travel Cost Surface.

Figure 5-4 shows the cost surface output. The cost surface is a raster that describes how difficult is for the people to travel through different paths in Redlands. Areas closer to roads were assigned the least cost value which are shown in dark gray color. Other areas were excluded from the least cost paths by giving higher values, shown in yellow and coral. The Extract tool was then used to create a mask to limit the following analysis to the cost surface inside the Redlands boundary.

Figure 5-4. Cost Travel Surface.

5.3 Calculating Cost Distance

The Cost Distance is a Spatial Analyst tool used to calculate distances to features along the least cost paths. For this project, cost distances were calculated from every cell in the output raster to the elements of interest (facilities, amenities, services, safeties and transportations). The Cost Distance tool considers the lowest values (the least cost path) on the cost surface to calculate distance from any cell to the targeted features (Figure 5-5).

Source: Google Images

Figure 5-5. Example of Travel Cost Surface and Path.

Figure 5-5 shows an example of least cost path generated from a cost surface. The bigger circles represent the highest cost cells and the smaller ones indicate the least cost cells. From least cost cells it is possible to define a least cost path which is represented by black lines in the figure. On the other hand, blue lines show the presence of rivers, which are the hardest path to travel through.

Figure 5-6. Cost Distances to High Schools (ft).

Since the cost surface was produced based on the Redlands roads, the least cost path in fact represents the shortest path along the street network. Figure 5-6 displays the cost distances from any locations in Redlands to local schools (high schools). The distances on the street network range from 0 to 80,191 ft. The gray color indicates the areas closest to the schools, while the purple areas represent the areas farthest away from the schools.

5.4 Fuzzy Logic for Suitability Analysis

Generally, spatial phenomena are continuous, but are often represented as discrete. When representing continuous phenomena with discrete approach, uncertainty is often involved and therefore discrete models lack precision in modeling the real world.

The decision to change the land use zoning of the Redlands Mall location from commercial to mixed land use requires analyzing the proximity of Redlands Mall to different features of interest. For example, according to the City of Redlands, the downtown area would be suitable for mixed land use if there are restaurants within 0.5 miles, which is considered to be an acceptable walking distance. The concept of “0.5 miles” is vague in this case, as a restaurant may still be accessed by residents if it locates 0.55 miles away from home. Thus, whether a restaurant is regarded as accessible to residents is uncertain due to the vagueness embedded in semantic meaning. In a discrete approach, a place is deemed to be unsuitable for mixed land use as long as there are no restaurants within 0.5 miles, even if many restaurants can be found within 0.55 miles. In this case, the use of discrete values, such as 0.5 miles, could lead to loss of valuable information and alter the results of the suitability analysis. An alternative to this discrete approach is fuzzy logic. Fuzzy logic is a mathematical framework for dealing with uncertainty in data (Lodwick, 2008). Fuzzy logic replaces the discrete boundaries between classes with a smooth transition derived from continuous values. In this project, fuzzy logic was applied to evaluate how suitable a location is for mixed land use based on the predefined criterion for each factor.

5.4.1 Fuzzy Membership

Membership functions for a fuzzy set aim to deal with uncertainty present in clustering data through classification (Singpurwalla & Booker, 2004). These functions can be defined as:

$$\mu_N: X \rightarrow [0,1]$$

where μ_N refers to the membership function of the fuzzy set N where each component of X is mapped to a value between 0 and 1. This value represents the level of membership of the component in X to the fuzzy set N .

There are several types of membership in fuzzy logic. A trapezoidal R-function was used to measure suitability in this project (Figure 5-8). The ArcGIS Fuzzy Membership tool was used to implement this membership function.

Figure 5-7. Fuzzy Membership Function.

The membership function described in Figure 5-8 requires the specification of maximum and minimum distances. The highest membership value is assigned to the minimum distance, and the lowest membership value is assigned to the maximum distance, where c is the minimum distance, and d is the maximum distance.

Figure 5-8. Fuzzy Membership for Schools.

As an example, any location that is within 1 mile of a school in this project receives a membership value of 1 for that criterion, while the maximum distance from a school, which is equal to 80,191.7 feet, receives a membership value of 0 (Figure 5-9).

Figure 5-9. Application of Fuzzy Logic for Schools.

Translating the information from Figure 5-8 into a map, locations that are within 1 mile of a school, and thus receive membership values of 1 for that criterion, are depicted in red in Figure 5-9. The membership values for schools then gradually decrease towards the city boundary. This gradual drop-off is illustrated in the map with color transitions from red to yellow, and ultimately green (Figure 5-9).

Figure 5-10. Fuzzy Membership Type-Linear Transformation.

A screenshot of the ArcGIS Fuzzy Membership tool is shown in Figure 5-10. The default membership function implemented by the tool is a positive linear function, where membership value increases when distance increases. However, since the membership function for proximity in this project is a negative linear function, the Minimum value was inputted with maximum distance value while the Maximum value refers to the predefined value for best suitability. Continuing with the example for schools, the maximum value is 1, which was given to locations < 1 mile from a school, and the minimum value is 0, which was given to locations 80,191.7 feet away from a school.

Figure 5-11. Suitability membership for Bus Stops.

Figure 5-11 is an example of a membership map produced using the Fuzzy Membership tool for proximity to bus stops. According to the criteria, proximity to these features indicates better suitability, and therefore areas closer to the features have a higher membership values, while the membership value decreases with distance from these features. The output of the ArcGIS Fuzzy Membership tool is a raster map displaying the probability of being a member of the suitable class. The green color indicates to the lands that have higher suitability values. Meanwhile, the color changes smoothly from green to blue, reflecting a decrease in suitability (Figure 5-11).

Figure 5-12. Suitability Membership Calculation for Highways.

The criterion for highways is different from the other criteria because its condition for suitability is twofold; highways should be within one mile of residential areas, but not closer than 984 ft. This membership method is shown in Figure 5-12.

Figure 5-13. Explanation of membership function for highways.

Figure 5 -13 shows the method used to exclude the area within 984 ft. which reflect disturbances for residential and commercial activity. The most suitable areas will be between 984 ft. and 1 mile from a highway. Beyond 1 mile, the suitability of a location gradually decreases.

Figure 5-14. Applying 0 Value for the Distance from 0-984.

In this case it was necessary to apply a slightly different procedure to calculate the suitability of an area based on its proximity to its nearest highway. First, the Fuzzy Membership tool was used to calculate membership values for all locations in the city using “within 1 mile” criterion. Then, the cells with values less than 984 ft. were extracted from the most suitable area since this distance reflects non-suitable areas. In order to do that, the raster was entered into the ArcGIS Is Null tool to assign a value of 0 to those cells falling within the range of 0-984 ft. (Figure 5-14).

Figure 5-15. Suitability Membership for Highways.

Finally, this raster was multiplied to the previous Fuzzy Membership raster using Raster Calculator. This last step produced a final membership map excluding the area within 984 ft. from the highways. Figure 5-15 shows the membership map for highways. Areas within 984 ft. from highways are displayed in purple color, which refers to the lowest suitability membership. The gray color indicates areas with higher suitability (Figure 5-15).

5.4.2 Fuzzy Overlay

To perform a multi criteria analysis, two or more membership maps can be overlaid to produce an output that displays compound membership of any location that considers all the inputting criteria. After creating membership maps for all the criteria, the Fuzzy Overlay tool was run on the resulting maps. The input for this tool requires each membership raster as well as the overlay type. The overlay type refers to the operator that will be used to define the membership of the rasters. The operator types are AND, OR, PRODUCT, SUM and GAMMA.

Figure 5-18. Model for Suitability Analysis.

The tool was converted to Python script to design the user interface and set the parameters. This makes the tool dynamic and allows the client to input different criteria according to the purpose of the analysis. The complete process of the analysis was written in Python script to create a suitability tool and design a user interface. The workflow started with the creation of a geodatabase to store all of the results of this tool. After that, a mask option was included for the geoprocessing environment to limit the analysis inside the city boundaries. The cost surface was set as a parameter to calculate the cost distance for each criterion considering the city roads (Figure 5-19).

This tool is intended to let the client input different criteria to perform suitability analysis based on fuzzy logic. The number of input criteria depends on the client's needs and project purposes.

Figure 5-19. Python Script Parameters.

For the suitability analysis tool created in this project to operate smoothly, the condition WHILE was used to iterate the Cost Distance and Fuzzy Membership processes discussed above. Specifically, the Fuzzy Membership tool requires maximum and minimum values in order to standardize the distances transforming to values from 0 to 1. The tool derives maximum values automatically from the highest value of cost distance results. On the other hand, minimum distances have to be specified by the client or the user. Minimum distance refers to the most suitable area, and will be given a value of 1. Mostly, suitable distances are taken from the city regulations.

The Fuzzy Overlay tool was applied with operator AND to combine Fuzzy Membership rasters, taking only the least values and greater. Finally, the suitability tool requires the user or client to enter a name of the overlay output.

5.5 Summary

The suitability analysis was a multi-step process. First, criteria necessary to meet the requirements for mixed land use were defined, and then cost distances of each criterion were calculated using a cost surface based on a road network of Redlands. Next, fuzzy logic was used to measure the probability of membership for each cell relative to each criterion. The same process was applied for all criteria except for proximity to highways, required more sophisticated treatment. Additionally, all membership maps were combined with Fuzzy Overlay tool using the operator AND, which returned the overall membership value. Finally, a tool was created to automate the process by developing a model that made the analysis useful for the client and decision makers in the future.

Chapter 6 – Results and Analysis

The results of this project revealed that the Redlands mall location is suitable for a mixed land use of residential and commercial, given the criteria specified by the City of Redlands. The potential and the suitability of the location were highlighted for decision makers as evidence to support land zoning change.

The first section of this chapter describes the final suitability map and the value of suitability for proposed change to Redlands Mall. The suitability result was normalized by the population density of the city. Section 6.2 analyzes the accessibility to the basic services and the average daily traffic volume around the Redlands Mall location. Section 6.3 discusses the walkability issue and the application of mixed land use in downtown Redlands. This zoning change will enhance the walkability of area by decreasing car dependence as well as traffic accidents. Section 6.4 compares existing condominiums to potential residential buildings in the Redlands Mall location in terms of their accessibility to services. The last section explains the user interface of the tool created for the client.

6.1 Suitability Evidence

After applying the suitability analysis and overlaying the membership maps, a final suitability map was created. This map shows the most and least suitable areas for mixed land use development within the context of the criteria set forth by the client. Figure 6-1 shows that the west central part of the city (in white color) is the most suitable area for mixed land use as various services and facilities are concentrated in that area reflecting the future sustainability for mixed land use. Suitability decreases smoothly and gradually towards the edges of the city boundary because few facilities, amenities, and services are available. The Fuzzy logic and Fuzzy Overlay approach avoids a crisp limit and creates continuous boundary between suitable, less suitable, and least suitable areas.

Figure 6-1.Redlands Suitability Map

The Redlands Mall is located in a highly suitable area, given the criteria used in the analysis. This means that the Redlands Mall location is well-served by most of the targeted features needed for mixed land use. The suitability score of Redlands Mall is 0.97, which is a very good indicator for mixed land use.

As shown in the population density map (Figure 6-1), the highest concentration of inhabitants is clustered surrounding the center of the city, which indicates that that people are more likely to reside in more dynamic areas than areas with less urban opportunities. Developing a new mixed land use in the Redlands Mall will create more residential units for the people living nearby.

Figure 6-2. Population Density per Sq. mile in Redlands 2010.

6.2 Analysis of Downtown Area

Similar to most cities in Southern California, residents of Redlands are highly dependent on automobiles to access basic services. The daily average of traffic volume around the Redlands Mall is about 20 thousand vehicles per day. This volume of traffic brings serious consequences such as large number of traffic accidents in the downtown area. Figure 6-3 shows the distribution of traffic accidents in Redlands. It is obvious that downtown area attracts the people for its variety of services and facilities. In consequence, there is a high concentration of traffic accidents in this area shown in dark blue color. On the other hand, the volume of accidents outside downtown area is significantly lower.

Figure 6-3. Traffic Accidents Density per Sq. mile in Redlands 2012.

Given the downtown area is a high traffic zone, mixed land use in the Redland Mall location may significantly decrease traffic volume, as it brings people to the area and enhances their walkability to these urban opportunities.

In addition, analysis provided by www.walkscore.com gives the study area a score of 91/100, signifying that the Redlands Mall location is ideal for walkers. This is because it is within close proximity to many local restaurants, shops, grocery stores, parks and schools. Given the convenience to various facilities and services, www.walkscore.com predicts that the Redlands Mall is likely to be an appealing place for residents, which reinforces the suitability results derived in this project (Figure 6-4).

Figure 6-4. Walk Score.

Applying mixed land use would add a different dynamics to the downtown area by offering more walkable lifestyle and decreasing the reliance on automobiles.

In fact, the existence of the services close to the residential area would likely decrease the traffic accidents, as long as the area is provided with the necessary conditions for a walkable life, such as sidewalks and signs.

Figure 6-5. Location of Redlands Condominiums and Redlands Mall.

6.3 Redlands Condominiums Compared to Redlands Mall

In Redlands, there are existing complexes of condominiums located in areas that offer access to some amenities, but overall these spaces do not provide walkable access to a diverse range of opportunities. Figure 6-4 supports this claim by showing that the existing condominiums are located in the areas that have relatively low suitability scores. Stated differently, these areas are less suitable for mixed residential and commercial land use than the Redlands Mall site, based on their (in)accessibility to various urban opportunities. Therefore, bringing residents into the Redlands Mall location would provide residents with easy access to restaurants and shops, as well as other amenities and facilities. With those services within walkable distances, the new residential area has a high potential for creating a living space in a great location in downtown Redlands historic district.

6.4 Crime Suitability

While the Redlands Mall location was found to be highly suitable for mixed use development relative to the criteria specified by the City of Redlands, one criterion that did not factor into the client's requested analysis was crime. However, to the extent that crime creates an inhospitable residential environment, it seems necessary to supplement the prior suitability analysis with this criterion. Toward that end, Figure 6-6 presents a suitability layer based on crime density in Redlands. As the map clearly demonstrates, the Redlands Mall location is much less suitable for residential land uses when one factors in the high concentration of crime in the downtown area. In this context, redevelopment of the location for mixed use purposes might require initial increases to security investments, so that incoming residents feel safe. Once the area is fully redeveloped as a functioning mixed use environment, though, it is highly likely that crime will decrease around the Mall area.

Figure 6-6. Redlands Mall with Crime Suitability

6.5 Suitability Tool

A critical part of this project was to build a tool that automates the processes involved in carrying out suitability analysis based on fuzzy logic. The tool was created to be accessible for the client and other city officials, so that they can quickly make evidence-based decisions related to land use zoning and area-based planning within a GIS framework. This tool includes a user interface that allows the client to specify the path that the new geodatabase is to be stored. Once this path is specified, a geodatabase in which to save all of the outputs from the suitability analysis is created. This geodatabase will store not only the final output of the suitability analysis, but all results from partial steps as well, (e.g., Cost Distance and Fuzzy Membership). This step allows the client to access and check over the results from every procedure undertaken in the analysis.

Within the suitability tool, a cost surface is required for the calculation of the Cost Distance. The cost surface must be based on the presence of roads, streams, rivers, and any other elements that would affect the transit of people around a certain area. Accordingly, the user interface asks the client to input a cost surface raster that represents the level of difficulty involved in traversing the city. Next, the user is asked to set the Mask for the analysis. This environment parameter limits the analysis (and resultant outputs) to the desired area. In this case, the Redlands city boundary was used as the mask to limit the suitability analysis to Redlands city. The cell size was set as an optional

parameter to give the client the opportunity to choose the level of detail for the analysis. In the case that the client does not input any cell size, the default cell size will be derived directly from the previous step in the analysis. Once the above information is specified, users input suitability criteria as well as their corresponding minimum distances. These criteria are required to calculate overall suitability relative to the specific purpose. The minimum distances are required parameters, and they allow users to set the distances to or from each criterion that describe suitable areas. During this step, the user specifies the criteria that are of interest to the given project, as well as the distances to or from each criterion that are associated with locational suitability. The first two criteria and their distances are required parameters, because the overlay tool needs at least two features to function. The rest of the criteria are optional, and whether they are specified depends on the users' needs. In the last step of the interface, the client will be asked to input the name of the final suitability output map. Because the tool functions in this general way, it can be used in different cities for a variety of suitability analyses, not simply those related to mixed use development (Figure 6-7).

Figure 6-7. User Interface.

6.6 Summary

This project conducted a suitability analysis based on fuzzy logic that depicts the most and least suitable areas for mixed use development in the city of Redlands, CA. Based on the client's criteria, the most suitable areas are located in the downtown area. The Redlands Mall location in particular has a suitability score of 0.97 on a scale to 1.0. Given the construct of fuzzy logic, this score indicates that Redlands Mall is one of the most suitable areas in the city for mixed land use development. This finding offers convincing support to the City's decision to rezone the Redlands Mall for both residential and commercial land use.

Chapter 7 – Conclusions and Future Work

This chapter summarizes and concludes the project, its process and how the required evidence of the client was obtained. The satisfactory completions of the client's functional and nonfunctional requirements are also discussed. The future work of this concept could focus on sensitivity analysis application. Furthermore, a deeper analysis of ArcGIS fuzzy tools is necessary to improve overall functionality.

7.1 Conclusions

This project performed a GIS-based suitability analysis to evaluate a redevelopment plan proposed by the city of Redlands, CA, to convert an existing commercial site into a mixed use environment. The study area, Redlands Mall, has been abandoned since 2007, but still maintains a large footprint in the historic area of downtown Redlands. In response, city planners and public officials aim to change the land use of the building which entails amending the municipal zoning code, to support a mixed use development project that seeks to make the former mall site a more vibrant place. The goal of this project was to provide evidence to the client that supported this decision.

To achieve the goal of the project, a suitability analysis was performed to measure the ability of the study area to support residential land uses. The criteria were mindful of the city regulations and specified by the client. Criteria were based on proximity to services, amenities, safety, facilities and transportation.

Suitability analysis is a widely used method in urban planning. However, in most cases the representation of phenomena is far from reality since it is based on a crisp logic. To avoid this situation, fuzzy logic was used to get a better depict reality. This method specifies the probability of any place in the city being member in the suitable areas. Steps had to be completed to prepare data to be appropriate as input for Fuzzy tools.

The results obtained showed continuous values indicating the suitability level ranging from the highest possible (1) to the lowest (0). According to the final suitability map, the Redlands Mall location received a high level of suitability which indicates its aptness for the application of mixed land use. A series of tools were combined in ModelBuilder to create a suitability tool with a flexible user interface to allow the client and others to use it in different areas and with different criteria depending on the particular needs. This project satisfied the client in terms of meeting functional and nonfunctional requirements.

7.2 Future work

The suitability analysis can be used for a variety of criteria and purposes. This analysis can be applied on a variety of purposes such as land use, agricultural, flood risks, housing, commercial, species habitat, land cover, etc. This tool could be used for different cities and enable planners and decision makers to use the data to get desired results from their data. A sensitivity analysis could be applied further to study the variations of the results with the modification of input data and criteria as well as evaluating criteria being applied.

The ArcGIS Fuzzy Membership tool has been scarcely used according to the literature reviewed. This situation impedes the ability to compare with other studies and further study the particularities and functionality of the tool. Since ArcGIS is the most used GIS software, it is important that future work focuses on the application of fuzzy tools to identify its strengths and weaknesses and make constructive criticism on the tool in order to improve its functionality.

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Appendix A. The Code for Suitability Tool

The code for tool:

```
# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
arcpy.CheckOutExtension("3D")

# Process: Create Personal GDB

output_gdb = arcpy.GetParameterAsText(0)
name_gdb=arcpy.GetParameterAsText(1)

personal_geodatabase=arcpy.CreateFileGDB_management(output_gdb,
str(name_gdb))

###Roads
Redlands_Roads = arcpy.GetParameterAsText(2)

##City boundary
boundary=arcpy.GetParameterAsText(3)
extent_mask=arcpy.GetParameterAsText(4)
cell_size=arcpy.GetParameterAsText(5)
##
tempEnvironment0 = arcpy.env.extent
arcpy.env.extent = extent_mask
tempEnvironment1 = arcpy.env.mask
arcpy.env.mask = boundary
euc_distance=arcpy.gp.EucDistance_sa(Redlands_Roads,
str(personal_geodatabase)+"\\Euc_Redlands", "", str(cell_size))
arcpy.env.extent = tempEnvironment0
arcpy.env.mask = tempEnvironment1

##Reclass
reclass=arcpy.gp.Reclassify_sa(euc_distance, "Value", "0 100 1;100 500
2;500 1320 3;1320 2640 4;2640 5280 5;5280 25000 6",
str(personal_geodatabase)+"\\reclass_euc1", "DATA")
extract=arcpy.gp.ExtractByMask_sa(reclass, boundary,
str(personal_geodatabase)+"\\Extract_Recl1")
##Criterion
i=6
j=7
list_overlay=[]
while i<=42 and j<=43 :
    input_criterion=arcpy.GetParameterAsText(i)
    Membership_type=arcpy.GetParameterAsText(j)
    if input_criterion:
        cost_name=str(input_criterion).split("\\")
        cost_name_final=cost_name[-1]
        tempEnvironment2 = arcpy.env.extent
        arcpy.env.extent = extent_mask
        tempEnvironment3 = arcpy.env.mask
```

```

        arcpy.env.mask = boundary

cost_distance_criterion=arcpy.gp.CostDistance_sa(input_criterion,
extract, str(personal_geodatabase)+"\\Cost_Dist_"+cost_name_final)
        arcpy.env.extent = tempEnvironment2
        arcpy.env.mask = tempEnvironment3

#Fuzzy membership

fuzzy=arcpy.gp.FuzzyMembership_sa(cost_distance_criterion,str(personal_
geodatabase)+"\\FuzzyMe_"+ cost_name_final, Membership_type, "NONE")
        list_overlay.append(str(fuzzy))
        i=i+2
        j=j+2

fuzzy_output=arcpy.GetParameterAsText(44)

fuzzy_overlay=arcpy.gp.FuzzyOverlay_sa(list_overlay,str(personal_geodat
abase)+"\\" +str(fuzzy_output).replace(" ","_"), "AND", "0.9")

```

The code below allows the client to set only the most suitable distance (within):

```

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
arcpy.CheckOutExtension("3D")

# Process: Create Personal GDB

output_gdb = arcpy.GetParameterAsText(0)
name_gdb=arcpy.GetParameterAsText(1)

personal_geodatabase=arcpy.CreateFileGDB_management(output_gdb,
str(name_gdb))

###Roads
Redlands_Roads = arcpy.GetParameterAsText(2)

##City boundary
boundary=arcpy.GetParameterAsText(3)
extent_mask=arcpy.GetParameterAsText(4)
cell_size=arcpy.GetParameterAsText(5)
##
tempEnvironment0 = arcpy.env.extent
arcpy.env.extent = extent_mask
tempEnvironment1 = arcpy.env.mask
arcpy.env.mask = boundary
euc_distance=arcpy.gp.EucDistance_sa(Redlands_Roads,
str(personal_geodatabase)+"\\Euc_Redlands", "", str(cell_size))
arcpy.env.extent = tempEnvironment0
arcpy.env.mask = tempEnvironment1

```

```

##Reclass
reclass=arcpy.gp.Reclassify_sa(euc_distance, "Value", "0 100 1;100 500
2;500 1320 3;1320 2640 4;2640 5280 5;5280 25000 6",
str(personal_geodatabase)+"\\reclass_euc1", "DATA")
extract=arcpy.gp.ExtractByMask_sa(reclass, boundary,
str(personal_geodatabase)+"\\Extract_Recl1")
##Criterion
i=6
j=7
list_overlay=[]
while i<=42 and j<=43 :
    input_criterion=arcpy.GetParameterAsText(i)
    input_minimum_distance=arcpy.GetParameterAsText(j)
    if input_criterion:
        cost_name=str(input_criterion).split("\\")
        cost_name_final=cost_name[-1]
        tempEnvironment2 = arcpy.env.extent
        arcpy.env.extent = extent_mask
        tempEnvironment3 = arcpy.env.mask
        arcpy.env.mask = boundary

cost_distance_criterion=arcpy.gp.CostDistance_sa(input_criterion,
extract, str(personal_geodatabase)+"\\Cost_Dist_"+cost_name_final)
        arcpy.env.extent = tempEnvironment2
        arcpy.env.mask = tempEnvironment3

        #Fuzzy membership

maximum=arcpy.GetRasterProperties_management(cost_distance_criterion,
"MAXIMUM", "")
        Membership_type = "LINEAR" +str(input_minimum_distance) +
str(maximum)

fuzzy=arcpy.gp.FuzzyMembership_sa(cost_distance_criterion,str(personal_
geodatabase)+"\\FuzzyMe_"+ cost_name_final, Membership_type, "NONE")
        list_overlay.append(str(fuzzy))
        i=i+2
        j=j+2

fuzzy_output=arcpy.GetParameterAsText(44)

fuzzy_overlay=arcpy.gp.FuzzyOverlay_sa(list_overlay,str(personal_geodat
abase)+"\\" +str(fuzzy_output).replace(" ","_"), "AND", "0.9")

```

Appendix B. The Process for Each Feature