Automating Spatial Multi Criteria Decision Analysis (MCDA) of housing development sites in Richardson, TX using ArcGIS Pro SDK for Microsoft .Net – An accessibility level perspective.

by

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ABSTRACT

Right from the food we eat till the clothes we prefer to wear; our decision depends on various important criteria that we need to prioritize strategically. Similarly, in the contemporary world, the need for intelligent spatial decision making has gained a paramount importance. Let it be selecting a best place for building a new house or opening a new restaurant or relocating a company′ s office, every decision can make or break the business. Making wise decisions in industrial site selection and housing development sites by the government agencies needs a lot of attention and care that needs to be taken which is dependent on various decision factors. In the field of GIS, the process of Multi criteria decision analysis help us in deciding about the prioritization of our criteria. The current research is about utilizing GIS based multi criteria decision approach for mapping the accessibility patterns of development sites for housing in the Richardson, TX. The main idea of this research was to implement a modern desktop GIS based interface for performing automated multi criteria decision analysis. Out of the available MCDA methods, AHP was chosen because of its simplicity, wide acceptance in past literature. ArcGIS Pro was preferred over other GIS packages for making a plug in because of its high-level mapping capabilities and a multi core processing environment. Add-in frame work for AHP multi criteria decision method was done in a raster based GIS environment. The developed add-in serves like a plug and play tool for the users. The main goal of this research was to make the decision-making process simpler by automating the Multi Criteria Decision methods. This also minimizes the laborious calculation process involved in making decision process. Hence it helps the authorities in evaluating and prioritizing the probable housing development sites with respect to accessibility levels. In addition, an attempt was made to carry out sensitivity analysis besides AHP process, which helps us in knowing how the overall suitability is getting changed based on a percentage increase or decrease in weights.

Keywords: MCDA, AHP, GIS, Housing Development, Accessibility, ArcGIS Pro SDK

1. Introduction and Motivation for the research:

The motivation for this research started when finding about the homelessness situation in the US and the measures taken by the Federal Government to control it. As per the 2017 estimates of Housing and Urban Development Authority (HUDA) of the United States, there are approximately 553, 742 people who are homeless on a single night in the US. According to HUDA, families with only one full-time worker couldn′ t afford rent for a two- bedroom market-priced apartment anywhere in the country. As per National Law Center for Homelessness and Poverty, the major reasons for the homeless situation are Poverty, Unemployment, Lack of Affordable Housing, Serious Health Problems, Family Relationships, Domestic Violence and Sexual Abuse.

In order to address the problem of affordable housing, the Section 8 housing scheme was introduced by HUDA. This scheme was introduced to help the low-income households. The government authorizes the rental assistance to landlords on behalf of the 11.9 mi low income households. Section 8 housing is administered by Public Housing Agencies (PHA′ s). To be eligible for section 8 housing, the family′ s income should be less than 50% median household income of the respective county or MSA. It is also mandatory for PHA′ s to provide 75% of the vouchers to families whose income is less than 30% of median household income. This can lead to gaps making the requirements tighter.

Section 8 housing helps the poor-*But only if the housing is available*. Hence is there a need for affordable housing? If so on what factors planners select sites for housing development. The first one obviously being geological conditions. Next comes the accessibility into play. Where accessibility to various basic facilities like transit, education, emergency, grocery is required. Are there any decision-making tools which can aid planners in the decision-making process? How can these tools help planners in evaluating multiple conflicting criteria?

When making any new construction, the accessibility to various services, facilities and amenities are taken as an essential factor which in turn affects the evaluation of housing development sites. Whether to choose a particular site or eliminate it, a proper informed decision needs to be taken based on all the accessibility factors. Most of the urban planners ensure that the individuals should have at least minimum levels accessibility to the public facilities like schools, emergency services, transit stops and recreation amenities. The outcome of this research primarily depends on what accessibility means to us during selecting sites for housing development.

In this paper "Accessibility is defined as the ease with which any sort of land use activity or facilities that can be reached either by transportation or by walk". In analyzing accessibility maximum and minimum distances were considered to any facility. The major goal of accessibility analysis is to minimize the travel cost for the customers and those who are very far. Geographic Information systems has been applied to analyze the accessibility for majority of the public services.

This research emphasizes on accessibility to various public facilities like schools, hospitals, grocery stores, bus stops, emergency facilities. As described earlier about the maximum and minimum distances, these are essential for exploration of geographical reachability. The maximum distance measures the degree to which the residents should have to travel the farthest to reach a facility. On the other side, the average distance measures the average distance that the residents living in a neighborhood needs to travel. Our main attempt in the research is to minimize the maximum distance that should be reached by a resident for accessing a facility.

In this study, the evaluation, classification and prioritization that needs to be made for selecting the potential housing development sites needs a thorough analysis. How can the housing development sites bring an impact in the living of residents? What should be weighed higher while mapping accessibility, what can be ignored? To address all these questions, we have chosen GIS based MCDA (Multi-criteria Decision Analysis) for solving the problem. AHP was chosen as the MCDA algorithm for performing multi criteria analysis. In addition, "What-if" analysis a.k.a "Sensitivity analysis" was performed know how the site suitability changes based on the increase or decrease of weights of the chosen criterion.

The major objectives of this research are:

1) to study and examine the method of AHP for site suitability analysis.

2) to develop a modern desktop GIS interface for carrying out the AHP process which could be applicable for any chosen theme.

3) to perform sensitivity analysis for identifying the suitability changes that happen if we increase or decrease weights of the criteria.

2. Literature Review

2.1 What is MCDA?

Multi Criteria Decision Analysis (MCDA) is the most valuable tool for evaluating multiple conflicting criteria and finally reaching a decision. It is widely applied in solving problems where choice is an alternative. MCDA has gained a huge popularity in Spatial Decision Support System.

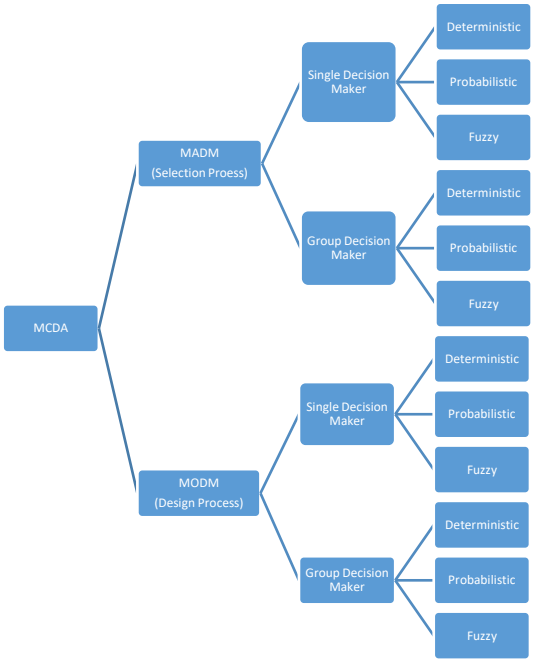


Figure 1: MCDA Classification

The Multi Attribute Decision Making (MADM) is performed if we require a discrete and finite solution space. On the other hand, for Multi Objective Decision Making (MODM) requires a continuous and infinite solution space. Over the last few decades, a greater research was carried out in MCDA and many new algorithms and methods were introduced year by year. Some of the major ones are Analytical Hierarchy Process (AHP), TOPSIS (Technique for order of preference by similarity to Ideal solution), ELECTRE (Elimination and choice expressing reality), Goal Programming, Weighted Sum Model, Weighted Product Model, Ordered Weighted Averaging (OWA). The different methods like AHP, VIKOR, TOPSIS etc are MADM methods where as LPP, Goal Programming are MODM methods. In short, the deterministic problems have certainty involved. Whereas the probabilistic problems involve randomness and the fuzzy problems involve inherent imprecision. The MODM usually follows the vector based GIS approach, whereas the MADM follows raster-based.

As already mentioned in section 1, AHP is used in our research because of the flexibility it offers and also the ease of understandability in terms of pairwise comparison. Hence a raster based analysis was

carried out in the research emphasizing the automation and integration of AHP into GIS software packages.

2.2 Concept of AHP:

AHP was initially developed by Prof. Saaty for helping people to make some complex decisions. Gradually, the power and simplicity of AHP was accepted world-wide and the method usage became widespread. The first and foremost step in an AHP is to divide the given problem into a hierarchy. In this the top level, will always be the goal that ultimately needs to be achieved. In this research, we have taken a three-level hierarchy. A pair wise comparison method was used to generate weights for the criteria that were considered. This methodology employs the concept of scaling developed by Prof. Saaty which have the odd values usually ranging from 1-9 when comparing two elements. A value of 1 is given if the two elements that are compared are same. For example, if criteria p is slightly important than q, then p is provided a 3 scale and q will be provided 1/3. Similarly, the process is carried out for other pairwise comparisons of the criteria. Rarely, if there is an ultimate need the intermediate even values 2,4,6,8 between two adjacent intensities are also used. The pairwise comparison matrix is generally of the form: $M = [x_{ab}]_{n\times n,}$ where x_{ab} is the pairwise comparison matrix for attribute a and attribute b. The matrix M is reciprocal that is $x_{ba} = x_{ab}^{-1}$. With respect to this condition, usually only n(n-1)/2 actual possible pairwise comparisons are required for a n*n matrix. Once we provide the rankings based on the Saaty scale, the computation of weights is carried out. This is done by a) Normalizing, which means dividing the elements by the sum of the columns b) Then the average of the obtained normalized values is calculated row-wise by dividing the sum of the row with the number of values in a row. Finally, the overall priority score is calculated by multiplying the weight values with the attribute values. It can be represented in the form of an equation:

$$R_j = \sum_{i=1}^{n} w_i . x_{ij} \qquad \text{--- (1)}$$

Where w_i is the object and attribute weights which is obtained by the standardized AHP process which was done above and x_{ij} is the standardized attribute value for the j-th alternative. Now a consistency check should be performed to know if our obtained weights are consistent enough to proceed with the MCDA analysis. To perform this operation, we initially obtain the consistency index (CI) and then divide it by random index(RI) to get the consistency ratio. If the consistency ratio is less than or equal to 0.1 then the weights chosen are good enough to proceed for performing AHP analysis. For obtaining the consistency index we perform the following steps: 1) multiply each row of the pair wise comparison matrix by the corresponding weight matrix (n ×n matrix with n×1 matrix). 2) Divide sum of the row entries by corresponding weight. 3) Compute the average value from 2 and denote it by λ. The approximate CI is then given by $CI = \frac{\lambda - n}{n-1}$, where n is the order of matrix. To obtain the consistency ratio, we divide the consistency index with the random index. Random index as per Saaty, 1980 is defined as follows:

n	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RI	*0.00*	*0.00*	*0.58*	*0.9*	*1.12*	*1.24*	*1.32*	*1.41*	*1.46*	*1.49*

If we obtain a perfectly consistent ratio, then the consistency measures will be equal to n and therefore, the CI′s will be the equal to zero and so the consistency ratio. Any higher value that 0.1 needs a reexamination of assigned preference ratings.

In the past papers and research work reviewed, the AHP process was carried out using the regular systematic calculation which requires a considerable amount of time for processing. The assignment of values using the Saaty scale, multiplication of matrices, normalization of matrices and average calculation requires a careful attention in processing the values. In this research, we would like to automate the process by the development of ArcGIS Pro SDK add-ins for the AHP calculation. Even though tools were developed in the past for AHP calculation, there were still some redundancies which could have been eliminated to improvise the tool′s functionality and the speed of execution. In this research, we tried to address this by developing a tool which allows the user to interactively select the criteria and assign preference ratings to them based on Saaty scale and finally calculate their weights. obtain, the concept of inverse calculation of the element values was also introduced which can significantly reduce the time of calculation.

2.3 Scholastic works reviewed:

Xuan Zuh *et al.,Sep 2005* explained in their study how a multi criteria framework for accessibility analysis was designed from a resident′s perspective in Singapore. Some of the criteria that were considered for accessibility analysis were Transit, Shopping Centers, Health care, Banks, Schools, Post offices. An Arc View extension called Accessibility Analyst developed by *Liu et al (2004)* was used in this process. An MCDA model was built using Java AHP (*Zhu et al, 2001*) process based on SMART (Simple Multi Attribute Rating Technique) method. The results were generated as hexagonal tessellations for observing varying patterns of accessibility criteria. Finally, the overall attractiveness of an area was visualized the overall attractiveness of an area from a demand-side perspective. A depiction was made that 10 zones out of the available 256 zones in the study area have the highest overall accessibility. Some of the limitations that were found are the emphasis was entirely on spatial aspects which limited the research. In addition, there was an automation deficiency that could have helped if incorporated in making real time simulations for the sensitivity analysis.

Y. Chen *et al., 2010* analyzed how GIS based MCDM with sensitivity analysis procedure are crucial to understand decision making model behavior and its limitations. A simulation based model was developed for observing the suitability changes in the spatial dimension. ArcGIS Engine 9.2 (ESRI 2008) platform was used to visualize the result. MATLAB COM- compliant DLL was used in the development

of framework. One-at-a-time (OAT) method was used for varying criteria weights for performing sensitive analysis. A visualization was created showing irrigated crop land and the relative changes in the suitable areas using raster based analysis. In addition, it also showcased which parts of the catchment area have poor soil texture, low hydraulic conductivity, undulating surfaces. There were limited insights into spatial patterns of weight sensitivity. The simulation based model also needs an update with the development of new ESRI desktop GIS applications.

Yunliang Meng *et al.,2011* in their study explained about concept of mapping accessibility patterns using AHP and OWA technique in Canmore, Alberta. The study was initially developed for AHP technique but was compared with OWA technique in a raster based GIS environment. The study also incorporated linguistic quantifiers as a method for obtaining weights. An expert from the Planning Department of Canmore was consulted to provide judgements regarding the relative importance of objectives and attributes. In the OWA process fuzzy linguistic quantifiers (At least one, Few, Some, Half, Many, Most and All) were utilized for a series of accessibility evaluation outcomes. This model comparison helped the housing authorities in addressing the uncertainty involved in the decision-making process. It also assisted the housing authorities in evaluating, planning and prioritizing the potential housing development from the accessibility perspective. One of the major limitation found was the lack of automation to integrate the model directly into GIS software packages for analysis.

Yunliang Meng *et.al*, 2015 conducted a study on how GIS based multi criteria decision analysis can be applied for evaluating accessibility to public parks in Calgary, Alberta. The study used a weighted linear combination with entropy weighting method for obtaining the criterion weights. Nine major criterions were considered for evaluating the accessibility. Majority of them were distance based, population based and number based. A comparison of accessibility patterns in 2006 and 2011 was performed. The parks were categorized as Mini, Neighborhood and Community. For performing the accessibility analysis 3 distance based models were applied namely Covering Model, Travel Cost Model, Minimum Distance Model. A core-periphery pattern was depicted showing the accessibility to public parks in Calgary. The study concluded that residents of central and eastern parts of Calgary tend to have higher level of accessibility to public parks than those living in the peripheral neighborhoods. The entire study showcased how GIS-MCDA procedures are very much helpful for planning experts to analyze various scenarios. Some of the limitations found were the use of only population and level of physical access to parks in the study. The model calculations which were done using different methods involve a complexity which could have been automated.

3. Study Area, Data Capture and Tools

3.1 Choosing Study Area

The study area that was chosen for the multi criteria decision analysis was Richardson, TX. The primary reason being to analyze the current section 8 housing situation in this booming city and understand the affordable housing patterns. Hence when researched upon this issue, I found out that there were only 50 project based section-8 subsidized apartments in Richardson. So, what can be done to improve this situation in Richardson for better housing with all accessible facilities for the public to cater all the people? This made me to think of a way which suggests the suitable sites for housing development by mapping the accessibility patterns to various minimum required facilities.

Richardson, TX is one of the major cities in the counties of Dallas and Collin in the state US state of Texas. As per the ESRI tapestry segment, domination of population analysis, it is an affluent inner suburb of Dallas. It is the home for the reputed University of Texas at Dallas (UTD) and many telecom companies. As per the latest census 2017 data Richardson has a population of 113,347 approximately. The largest employment base of Richardson is provided by the insurance industry. Some of the insurance companies located in Richardson are the head-quarters of Blue Cross Shield of Texas, regional hub of GEICO, regional office of United Health Care and one of the hubs of State Farm Insurance.

Before collecting the data, we have analyzed what factors can lead a site suitable for housing development. Since accessibility to various facilities was the main research in this study, we have taken opinions from various city planners and real estate agents what criteria can usually lead to the development of a housing suitability site. Ultimately the goal was to maximize the accessibility to these facilities and minimize the travel distance required to access all the facilities. To evaluate the accessibility level of the housing development sites, the following were considered.

1. Accessibility to Educational Facilities
2. Accessibility to Public Transit
3. Accessibility to Parks
4. Accessibility to Fire Stations
5. Accessibility to Grocery Stores
6. Accessibility to Medical Facilities

All these criteria were considered as the criteria for using the MCDA AHP method.

3.2 Data Acquisition:

The data was collected as ESRI shapefiles from various sources like Richardson ArcGIS Open data portal (education, parks, fire stations) ESRI 2017 Business Analyst (medical and grocery facilities), Google Transit Feed Specification (GTFS) (Public Transit) system. For collecting medical and grocery facilities, Shopping Centers and Businesses layer of ESRI 2017 Business Analyst was taken into consideration and

all the facilities within the region of Richardson were extracted by using "Select by Location" query in Arc GIS. The collection of data for public transit system involved lot of work because there was no readily available resource for collecting all the bustop points and light rail station points from DART or ArcGIS open data portal of Richardson. Hence Google Transit Feed Specification system was taken into consideration. A detailed cross verification was done through DART to check and see what all bus routes are within Richardson and extract the bus stop points using Google Transit API. Only major transit bus stations and light rail stations were considered and used as a part of this research.

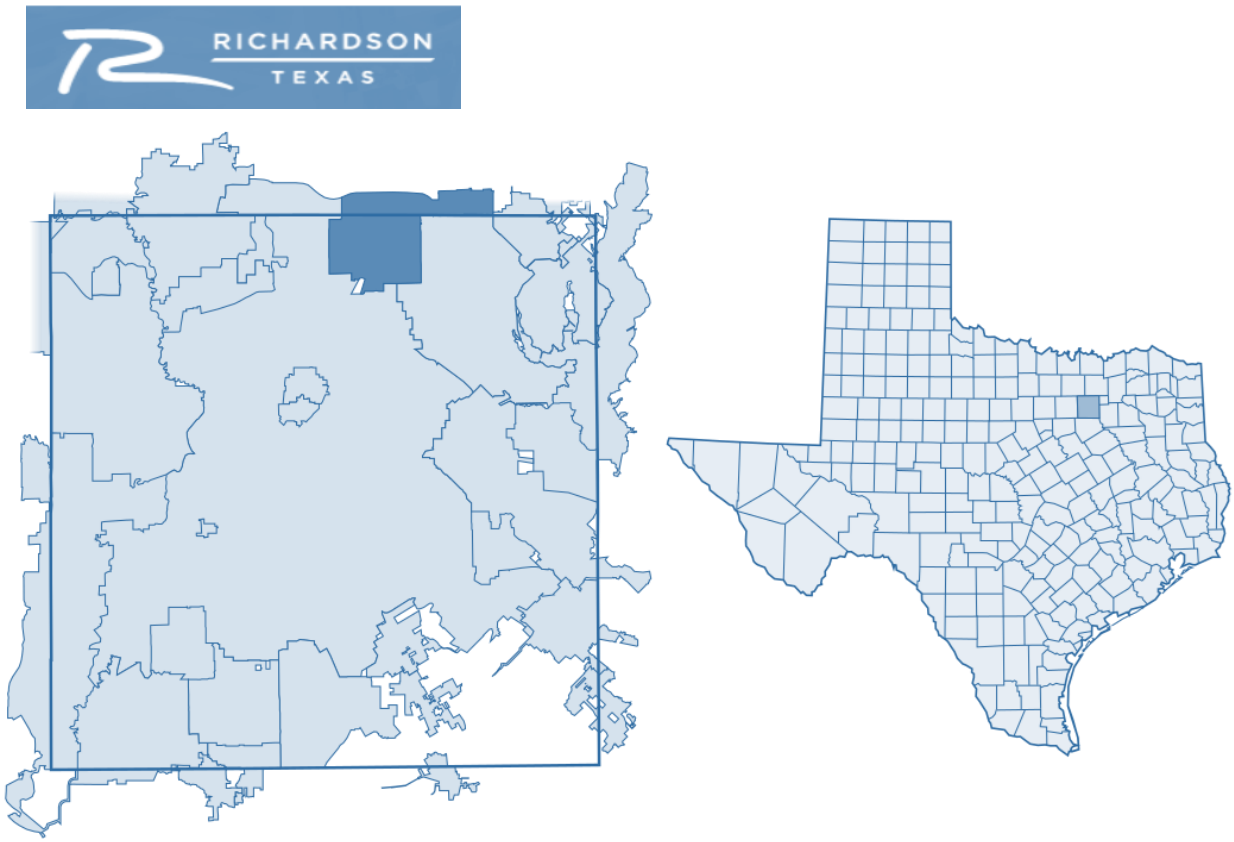


Figure 2: Texas State showing overview of Dallas County and Richardson

3.3 Tools and GIS applications used for development:

For developing an Add-in to be integrated to GIS software package, various GIS applications were studied like ArcMap, ArcGIS Pro, QGIS etc. Since ArcGIS Pro is the next generation desktop GIS, which has high level mapping capabilities like 3D, 2D advanced raster analysis, it made us interested towards the study and development of this Add-in for ArcGIS Pro. Some of the modern .Net features and patterns such as Task Asynchronous Programming (TAP), Language Integrated Query (LINQ), WPF binding and MVVM are used to for creating integrated 2D/3D add-ins using Pro' s new API.

4. Methodology and Tool Development

The methodology for this research is broken up into 3 major segments.

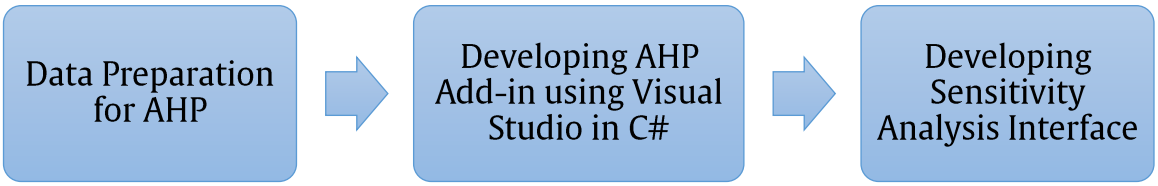


Figure 3: Flowchart showing the methodology

4.1 Data Preparation for AHP Process:

Before creating an AHP add-in for MCDA, we should decide on our criteria for analysis. Since our theme is to perform an accessibility analysis from the various criteria chosen namely educational facilities, parks, transit points, medical facilities and emergency facilities. The data preparation involves the following steps.

1. Importing all the criteria shapefiles into ArcGIS Pro.
2. Creating Distance Rasters using Euclidean Distance Tool and calculating statistics for them
3. Normalization of distance rasters to make the values fall between 0 and 1.

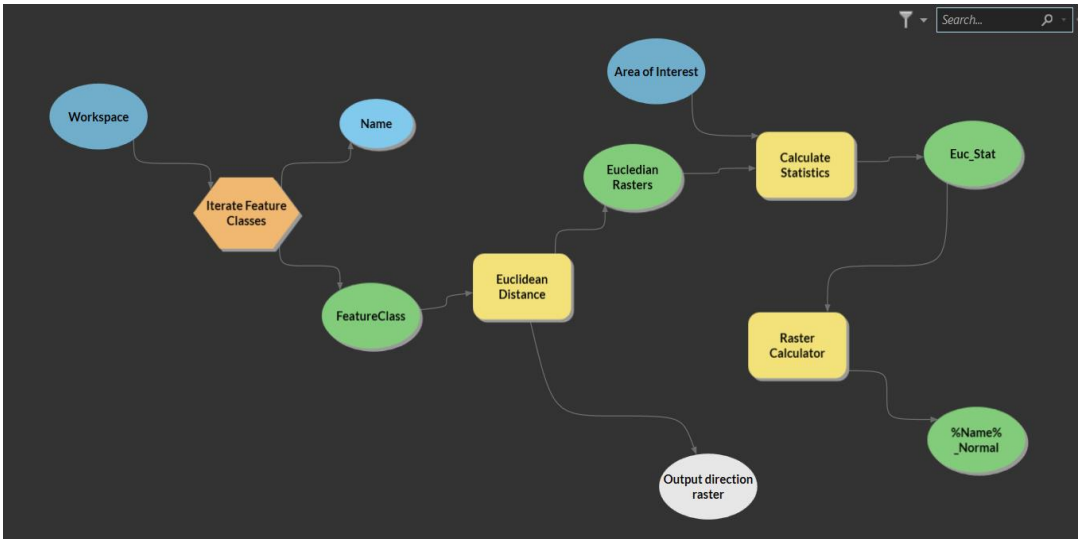


Figure 4: Model Built in ArcGIS Pro for initial data preparation of AHP

The above figure gives you an overview of how the normalized rasters are generated. As performing various geoprocessing operations on multiple rasters multiple times is a cumbersome process, I have taken advantage of the model builder in ArcGIS Pro which iterates all the shapefiles in the workspace, creates distance rasters for them, creates statistics for them and finally normalized rasters with values scaled from 0 to 1 are created.

For normalizing the rasters we have used the below equation in the raster calculator in ArcGIS Pro.

$$raster = \frac{raster - raster.minimum}{raster.maximum - raster.minimum} \ldots\ldots\ldots Eq\ (1)$$

If the above equation is used we get 0 assigned to highest accessibility and 1 assigned to least accessibility. But in this study, we wanted to use 1 for highest accessibility and 0 for least accessibility. Hence we subtract the Eq(1) from 1 which is

$$raster = 1 - \frac{raster - raster.minimum}{raster.maximum - raster.minimum} \ldots\ldots\ldots Eq\ (2)$$

Once we perform this operation, we get all the distance rasters and scaled from 0 to 1, where 0 represents the least accessibility and 1 represents the highest accessibility.

4.2 Development of AHP add-in using Visual Studio for ArcGIS Pro.

The next important step is to start developing the add-in for integrating it into ArcGIS Pro. In order to perform this, we can use the latest IDE of Visual Studio. Before writing code, we should make sure that our ArcGIS Pro SDK is installed from the Visual Studio Market Place, so that we can start building our Add-ins and integrate them to ArcGIS Pro.

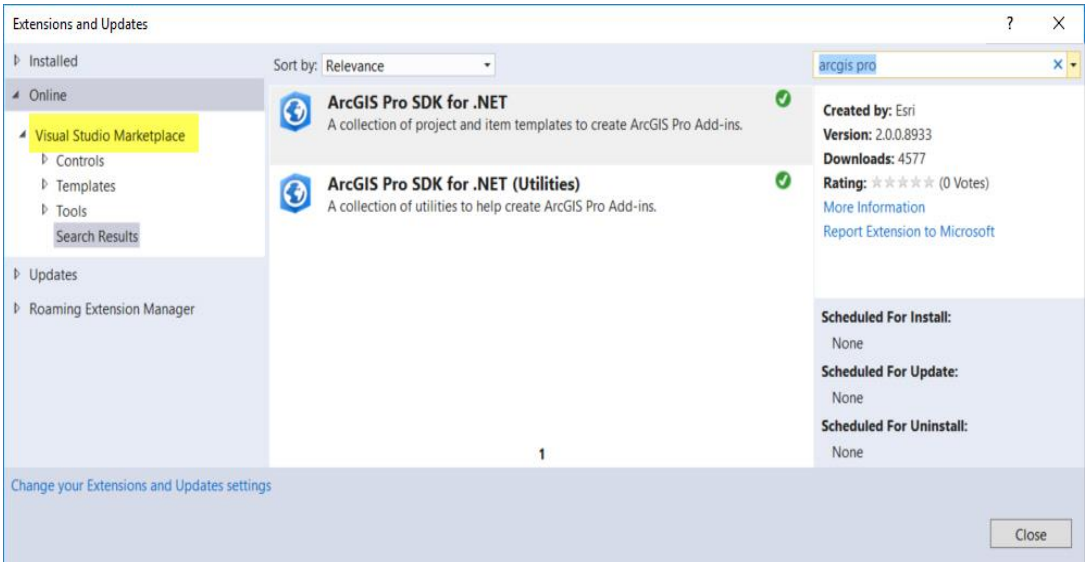
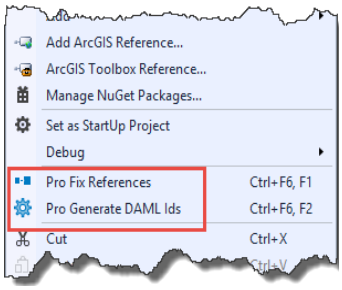


Figure 5: ArcGIS Pro SDK in Visual Studio Market Place



After installation, when we have any references issue, then we can right click on our project file and click Pro fix references which will make the mapping libraries to get recognized by the code and remove any compilation errors because of the imports.

Figure 6: Fixing Pro references in Visual Studio

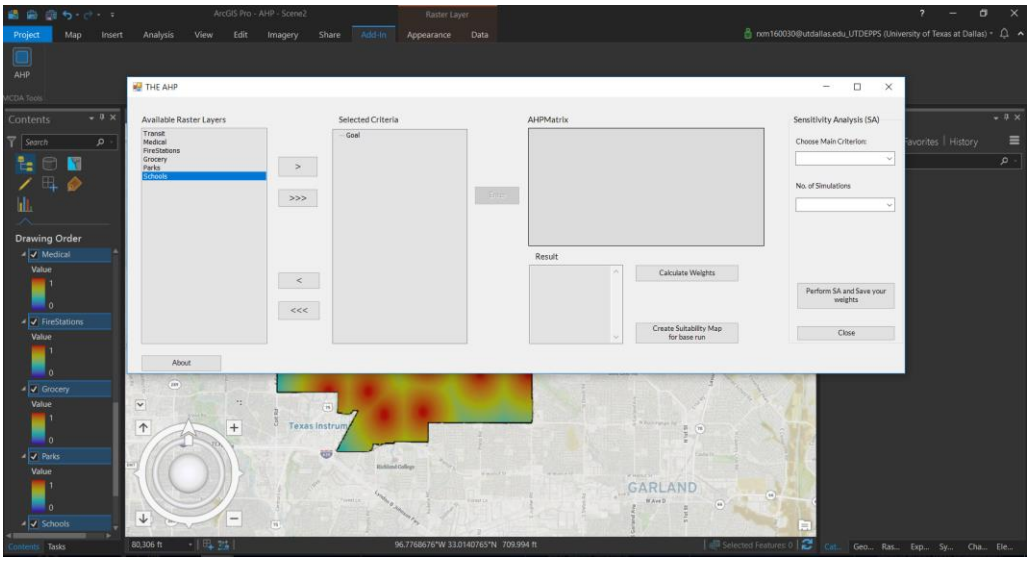


Figure 7: AHP add-in interface in ArcGIS Pro

Scale	Numerical rating	Reciprocal
Extremely importance	9	1/9
Very to extremely strongly importance	8	1/8
Very strongly importance	7	1/7
Strongly to very strongly importance	6	1/6
Strongly importance	5	1/5
Moderately to strongly importance	4	1/4
Moderately importance	3	1/3
Equally to moderately importance	2	1/2
Equally importance	1	1

AHP: Analytic hierarchy process

Figure 8: AHP preference ratings

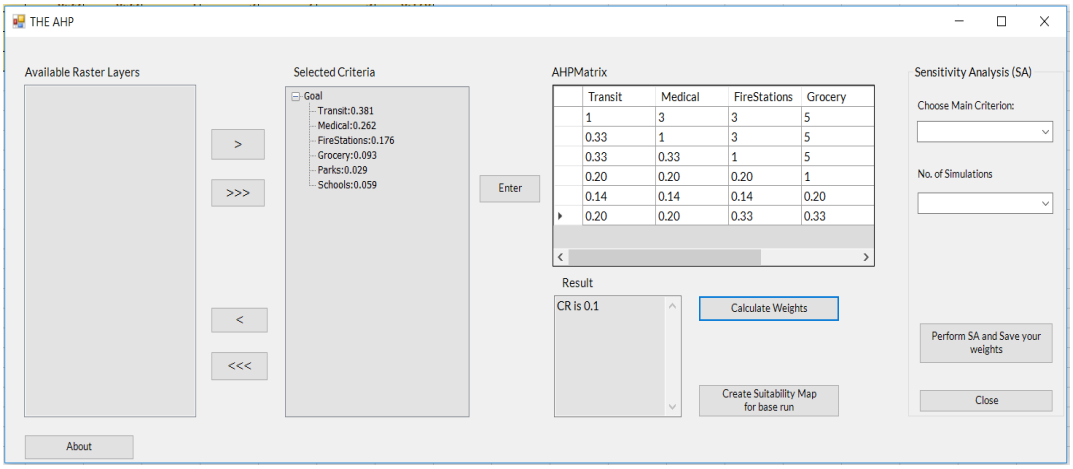


Figure 9: AHP Add-in interface with pairwise comparison matrix filled in.

4.2.1 Flow Diagram

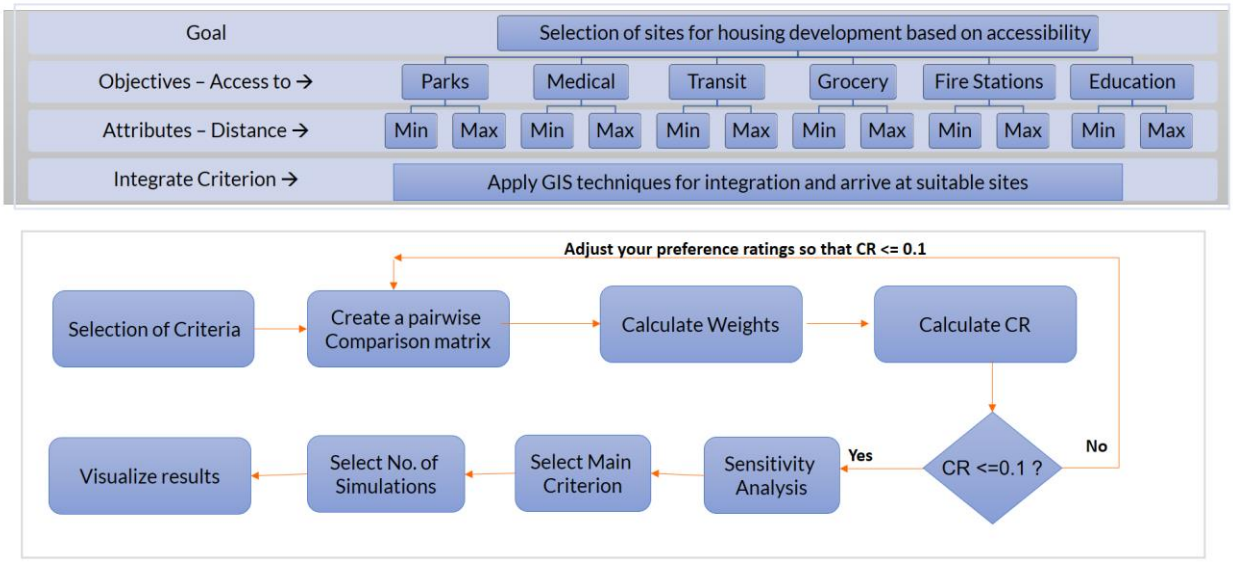


Figure 10: Flow Diagram depicting MCDA and AHP Process

The above flow diagram provides a brief schematic overview of MCDA process. In addition, we can also observe the AHP process about calculation weights. If consistency ratio is less than or equal to 0.1, then the weights are consistent enough to proceed to next step. If not, we should be adjusting our preference ratings as reviewed in the literature (section 2) to get a consistency ratio of less than or equal to 0.1. Once we obtain a consistency ratio, we can use the obtained weights to make a suitability map by invoking the weighted sum in the geoprocessing tool through our C# code written in visual studio. This will finally add the weighted sum layer to ArcGIS Pro and it can also be reclassified based on our requirements. For this research 0-0.6 is classified as "Low Suitability", 0.6-0.8 is classified as "Moderate/Medium Suitability", 0.8 – 1 is classified as "High Suitability". Since the weights assigned were user based and not fixed or constant, we could observe the relative change patterns in the suitability by increasing or decreasing the weights by a certain percentage which leads us to the new concept called as Sensitivity Analysis.

4.2.2 The concept of Sensitivity Analysis in MCDA:

Sensitivity Analysis can be simply stated as "Change and observe behavior". It is some-times referred to "What-if" analysis. This mean to find out what happens if there is an increase or decrease in the weight of a criteria. How does this affect the overall suitability or accessibility? Sensitivity Analysis is a powerful alternative for the method of indirect incorporation of uncertainties into decision making process. It is mainly concerned with the way in which errors in a set of input data affect the final

output. Sensitivity Analysis showcases the impact of changing criteria weights on the resultant output from the model in a spatial dimension.

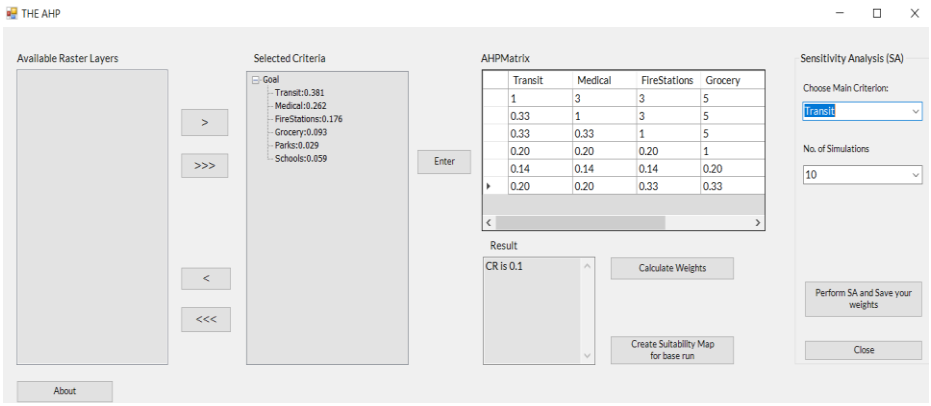


Figure 11: Sensitivity Analysis Interface Developed

The above figure shows a sensitivity analysis interface. Here we need to select one main criterion out of the available criterion and we should select the number of simulations that you want to perform. Then we can go ahead and click on "Perform SA and Save your weight" which will prompt us to save the weights in a csv file. For each simulation if the main criterion weight increases by x% then the other criterion weights will be automatically decreased by x% in order to maintain the rule of unity (sum of all weights = 1). For convenience, in this research all the increments or decrements are done in steps of 1. For example, if we select 2 simulations, we have two sets of results which are [1% increase (main criterion), 1% decrease (all other criterion)] and [1% decrease (main criterion), 1% increase (all other criterion)]. So, one simulation is a positive increase for the main criterion, the other one is negative increase (positive decrease) in the main criterion.

5. Results and Discussions

All the suitability maps that were generated by using the AHP add-in functionality were added in the Appendix section.

The sample preference rating matrix which is used for generating the weights for various criteria like Transit, Medical, Fire, Grocery, Parks and Schools is shown below:

Criterion	Transit	Medical	Fire	Grocery	Parks	School	Weights
Transit	1	3	3	5	7	5	0.381
Medical	0.33	1	3	5	7	5	0.262
Fire	0.33	0.33	1	5	7	3	0.176
Grocery	0.2	0.2	0.2	1	5	3	0.093
Parks	0.14	0.14	0.14	0.2	1	0.33	0.029
Schools	0.2	0.2	0.33	0.33	3	1	0.059

Figure 12: User preference ratings for criteria chosen

The consistency ratio obtained for the above sample matrix is 0.1. So, as per the Saaty rule of consistency we can use these weights for our suitability and sensitivity analysis. Below is the sample table generated when sensitivity analysis is performed. For this example, schools are considered as the main criterion and the other criterion are varied based on the weight variation of the schools.

% Change	Transit	Medical	Fire Stations	Grocery	Parks	Schools	Low	Medium	High	Simulation	Total Cells	Low to Medium	Medium to Low	Medium to High	High to Medium	Low to High	High to Low
-5	0.4	0.275	0.185	0.098	0.031	0.043	4915	30494	12049	1	47458	793	0	4563	0	0	0
-4	0.396	0.272	0.183	0.097	0.03	0.046	5088	31483	10887	2	47458	620	0	3401	0	0	0
-3	0.392	0.27	0.181	0.096	0.03	0.049	5220	32208	10030	3	47458	488	0	2544	0	0	0
-2	0.389	0.267	0.18	0.095	0.03	0.052	5339	32802	9317	4	47458	369	0	1831	0	0	0
-1	0.385	0.264	0.178	0.094	0.029	0.055	5544	33692	8222	5	47458	167	3	736	0	0	0
0	0.381	0.262	0.176	0.093	0.029	0.059	5708	34264	7486	6	47458	0	0	0	0	0	0
1	0.377	0.259	0.174	0.092	0.029	0.062	5829	34848	6781	7	47458	0	121	0	705	0	0
2	0.373	0.257	0.173	0.091	0.029	0.066	5915	35233	6310	8	47458	0	207	0	1176	0	0
3	0.37	0.254	0.171	0.09	0.028	0.07	6068	35785	5605	9	47458	0	360	0	1881	0	0
4	0.366	0.251	0.169	0.089	0.028	0.074	6218	36375	4865	10	47458	0	510	0	2621	0	0
5	0.362	0.249	0.167	0.088	0.028	0.079	6300	36746	4412	11	47458	0	592	0	3074	0	0

Figure 13: Table showing sensitivity analysis results

The number of cells that were changed from one suitability level to other suitability level are obtained by using the "Combine Rasters" Geoprocessing Tool. From the table, we can see that the 6th simulation

is the base run, the 1st simulation is 5% decrease in weight of schools criterion and corresponding increase in weights of other criteria, the 11th simulation is 5% increase in the weight of the schools criterion and corresponding decrease in weights of other criteria.

5.1. Accessibility Trend Analysis for Various Facilities:

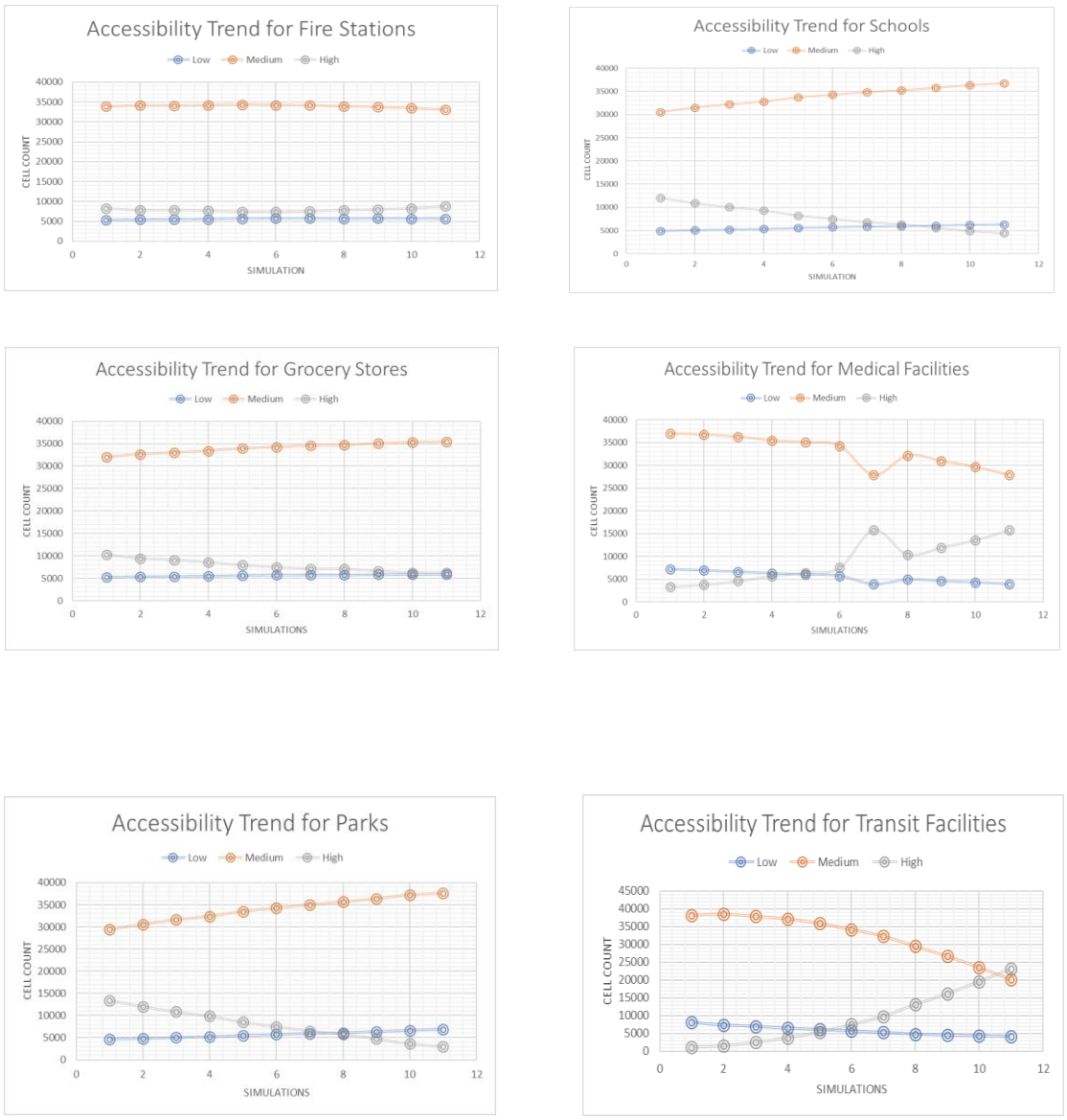


Figure 14: Accessibility trends varying with simulations.

Some of the key observations from the above graphs and the table are:

- There are no cells that have been increased/decreased more than one suitability level.
- Transit and Medical facilities are highly sensitive because they are given high importance in weightage criteria.

- Parks and Schools are having lowest sensitivity as they are given least importance in the weightage criteria.
- From the table we can also observe that the highest variation in the number of cells occurred in "Medium/Moderate suitability" and "High suitability".
- From the sensitivity analysis table, we can also observe that there is a dramatic increase in the cell count within ±5% change for the classes of "High and Moderate" suitability.
- The "Medium/Moderate and High" suitability classes are most sensitive to the criteria weight changes. There is also a clear cell exchange observed.
- From the base run reclass result which is 0% increase or decrease in weights, we found the below suitability levels.
    - 16% of the total area is highly suitable
    - 72% of the total area is moderately suitable.
    - 12% of the total area is less suitable

6. Conclusions, Limitations and Future Findings

6.1 Conclusions:

In this research, a generalized decision model was created for applying to any Multi criteria decision analysis theme. An automated Spatial MCDA tool for AHP was developed which can be embedded into latest desktop GIS application (ArcGIS Pro) unlike the outdated applications like ArcView, Engine (changed to ArcMap and ArcGIS Sever now). All the customization of the features were packaged in a single compressed add-in file (.esriAddInx) which can be shared easily without the need of any installations for ArcGIS Pro users.

Sensitive Analysis was performed with an intuitive approach for finding and analyzing the results. The primary objective of the sensitive analysis was to analyze how the suitability varies if these is an increase of decrease in the weights of the criteria that are considered. This helps the planners to know how and where the changes are occurring based on a single criterion change. Each main criterion selected yields different results in the sensitivity analysis. This tool saves a considerable amount of time in finding the suitability without the need of any manual calculations. Once all the inputs are provided in the correct and right format, then the add-in tool helps us to yield the results by just clicks and our judgements in assigning the preference ratings.

6.2 Limitations and Future Findings:

The major limitations and how they are going to be addressed in future are shown below.

6.2.1 The concept of subjectivity:

The usage of a subjective decision model (AHP) for assigning user preference ratings. We are not able to quantify the measures of the criteria that are chosen. This simply means "How much of one criterion is compared with the other criterion?" In order to address this problem, in future, other MCDA methods like OWA, TOPSIS, ELECTRE, Goal Programming, Compromise Programming will also be reviewed and analyzed. An attempt will be made to automate the MCDA process using different methods and make a comparison of the results obtained from them.

6.2.2 Land-use Landcover Verification:

After obtaining the suitability map showcasing the areas of high, moderate and low suitability there was no comparison performed with the land use land cover data. Hence in future, we would like to refine the areas which have higher suitability by using the overlay technique. The suitability map obtained will be overlaid with the most current satellite imagery products like GeoEye, Digital Globe, Spot Image, ASTER, Black Bridge, Image Sat International, Landsat, Sentinel-2 to have a clear and defined area of high suitability for housing development which will be of significant use to the planners and housing department authorities.

6.2.3 SME and Urban Planners Review:

All the preference ratings assigned in the weight matrix were taken as a part of the survey which did not include any SME or Urban Planners ratings which is very important while selecting sites. Hence in future we would like to take valuable inputs and feedback from the housing department planners while making the pairwise comparison of relative importance between criterion.

6.2.4 User friendly reclassification extension:

The reclassified suitability (accessibility as theme) map was generated using a predefine classification range as already mentioned in the methodology section. So, in future there is an idea of developing a plug and play reclassification tool bar in AHP, which helps the users to assign their own classification ranges while deciding on the levels of suitability. Even through "reclassify raster" geoprocessing tool can be used for this purpose, it is not directly integrated in the AHP add-in interface which will be addressed in future.

6.2.5 Open source GIS ideology:

Since the Add-in was developed using ArcGIS Pro SDK it can only be integrated to ArcGIS Pro and used in it. With the predominant demand for open source GIS in today's world, an attempt will be made in future to develop this plugin in open source GIS applications such as QGIS, GRASS GIS etc.

6.2.6 Automated graph generators:

All the accessibility trends that were depicted in results section were generated for observing the variation in the cell suitability with respect to cell count and suitability, were done manually without any automated techniques. In future, this limitation will be studied and addressed by using an Automatic graph generator with the help of Microsoft Graph API. This will help us to detect the various levels of suitability instantly with just a single button click.

6.2.7 Use of other distance based methods:

This study used the generalized Euclidean distance approach for performing MCDA analysis. There was no travel cost that was taken into consideration. This will be addressed in the future by utilizing other distance methods like network distance, cost distance in finding out the accessibility, thereby finding the resultant suitability.

7. References

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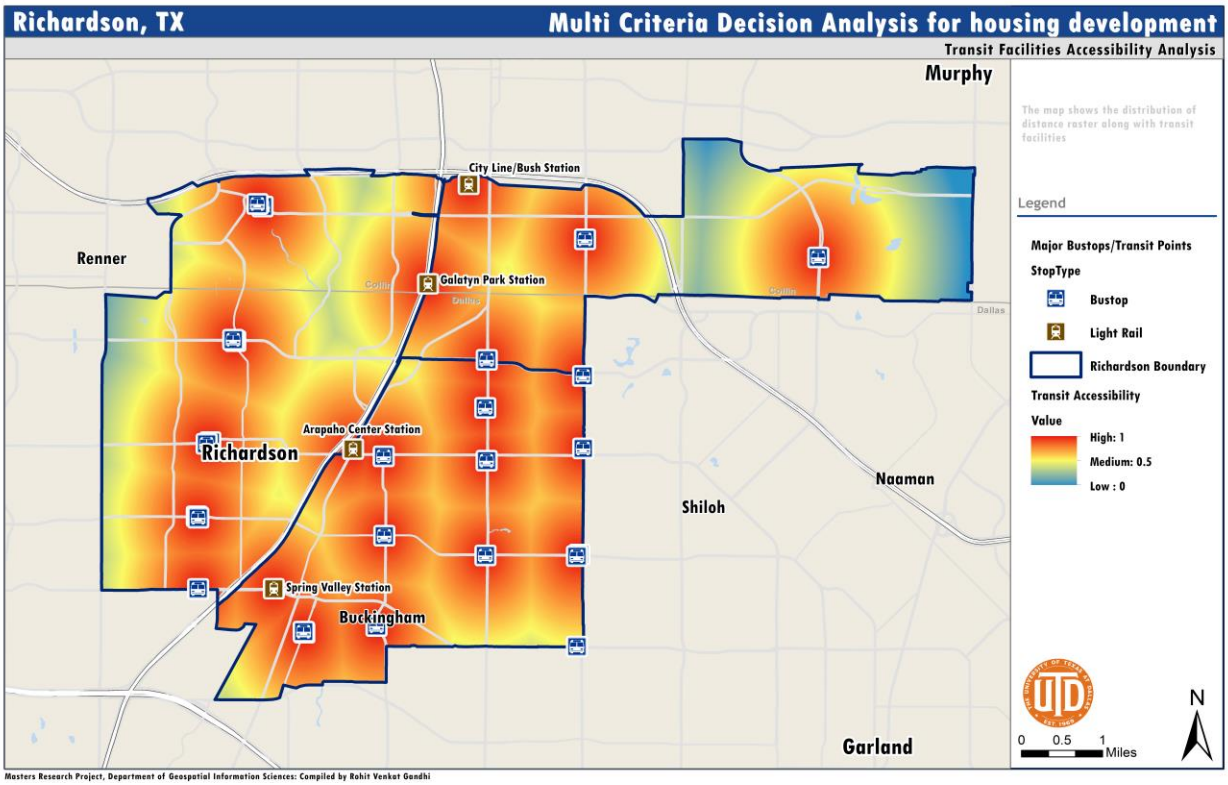
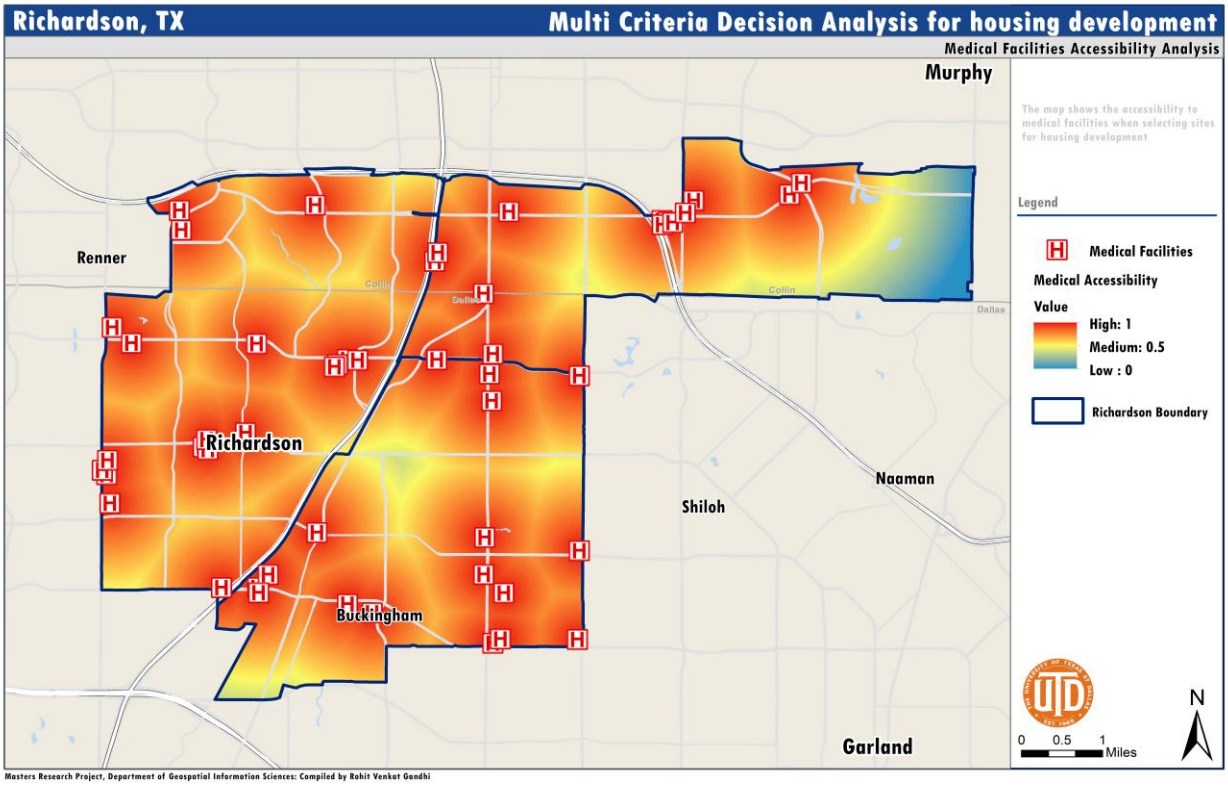
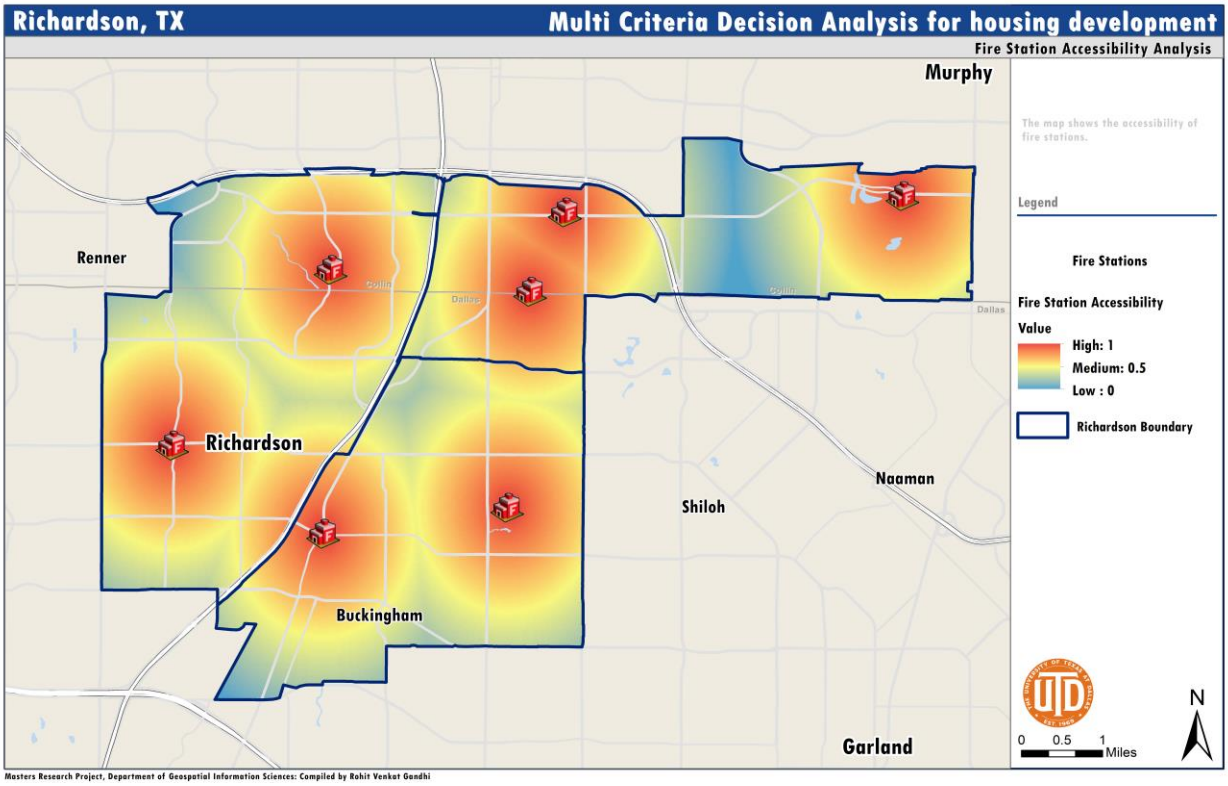
- Stack Overflow (https://stackoverflow.com/)
- ArcGIS for Developers (https://pro.arcgis.com/en/pro-app/sdk/)

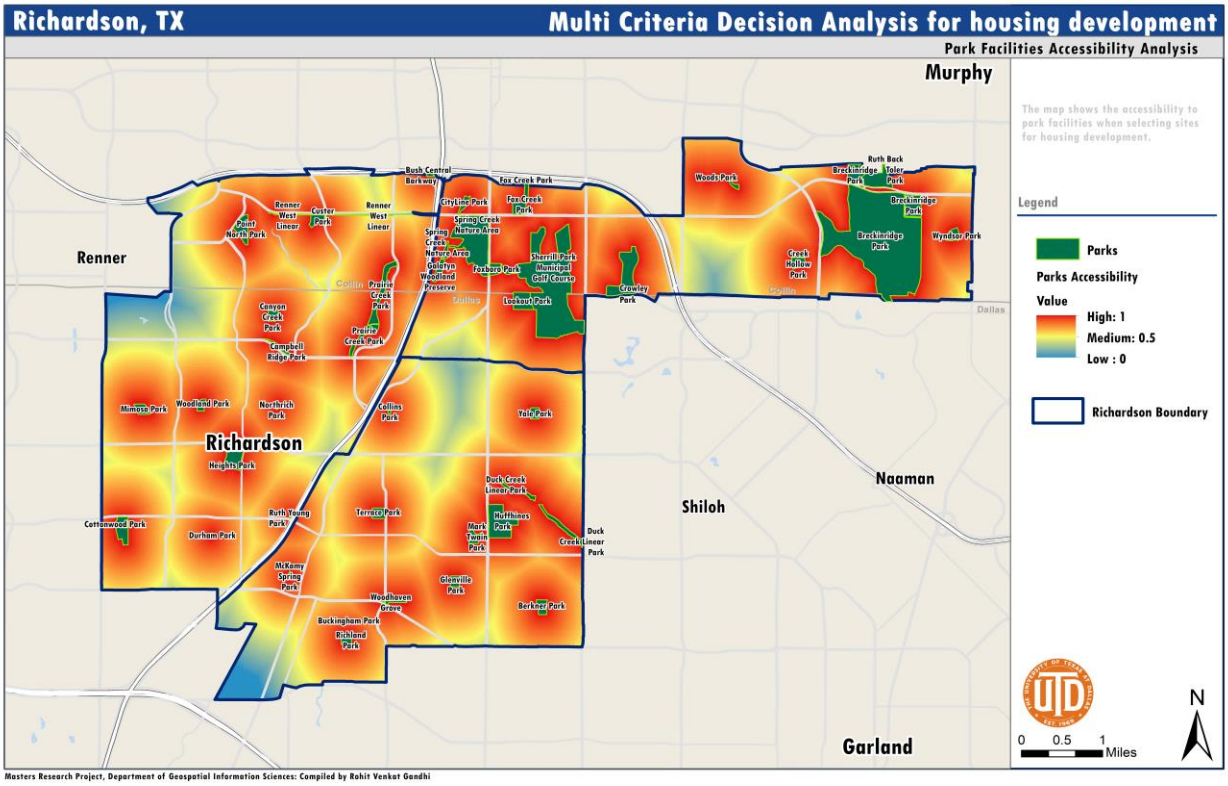
8. Appendix – Suitability Maps

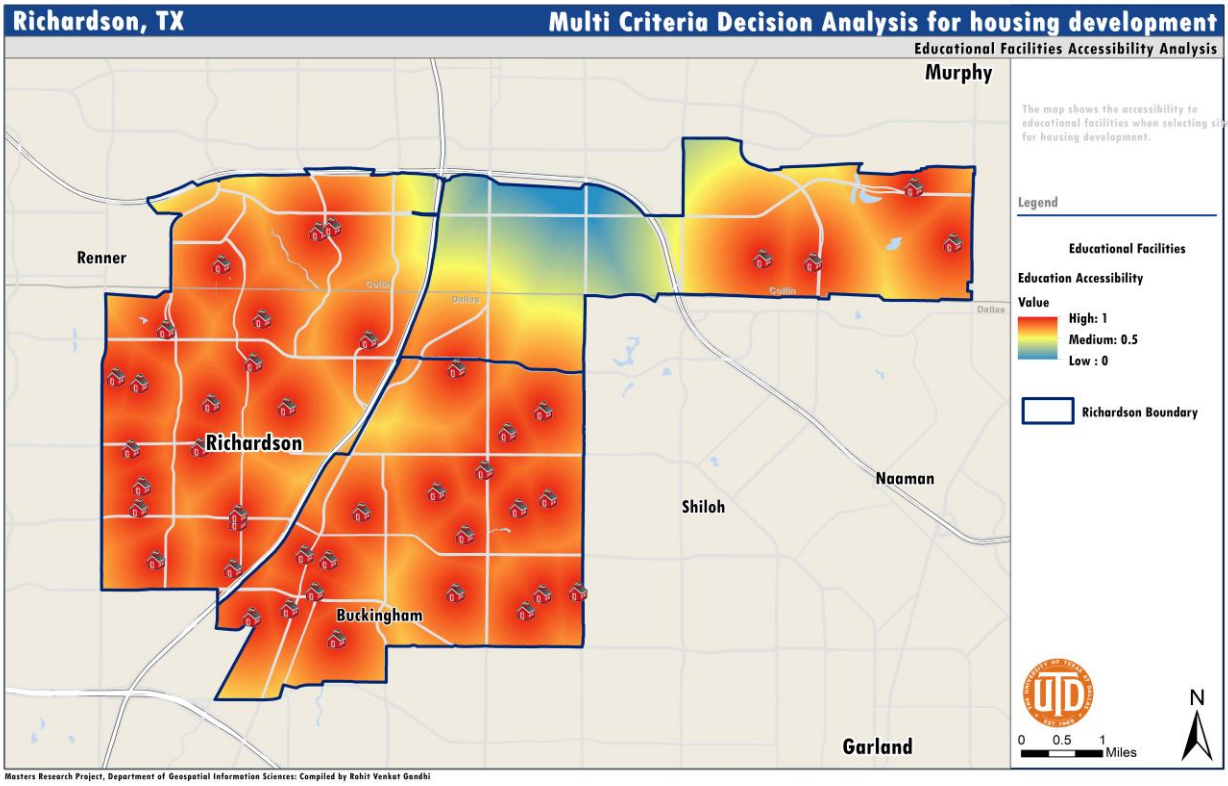
Note: All the maps are in WGS 1984 Web Mercator Projection

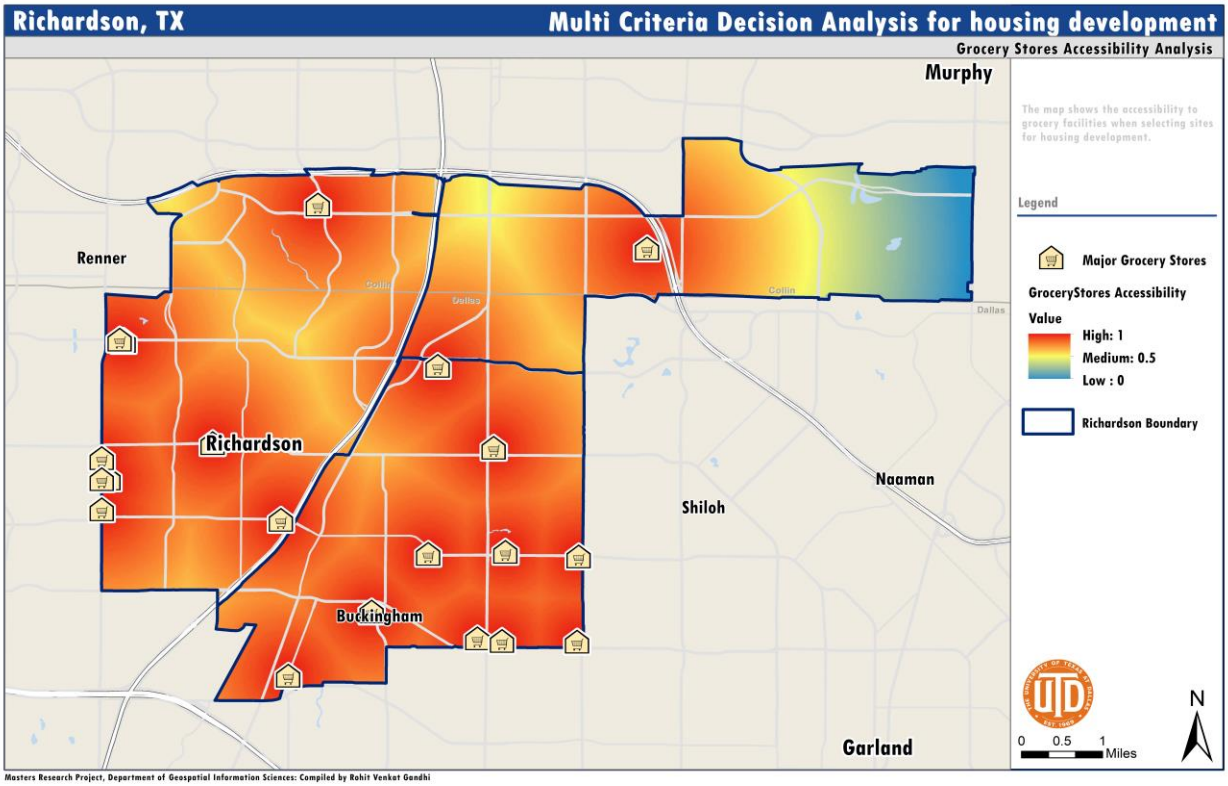


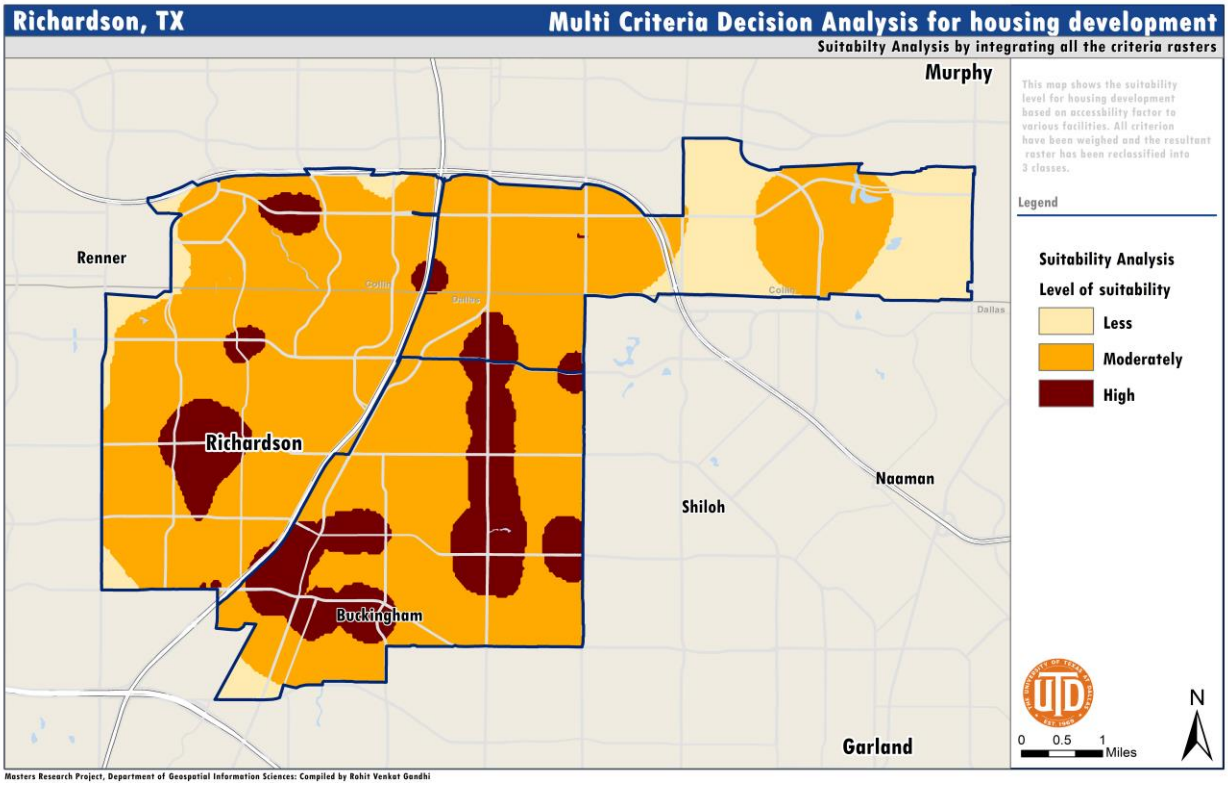


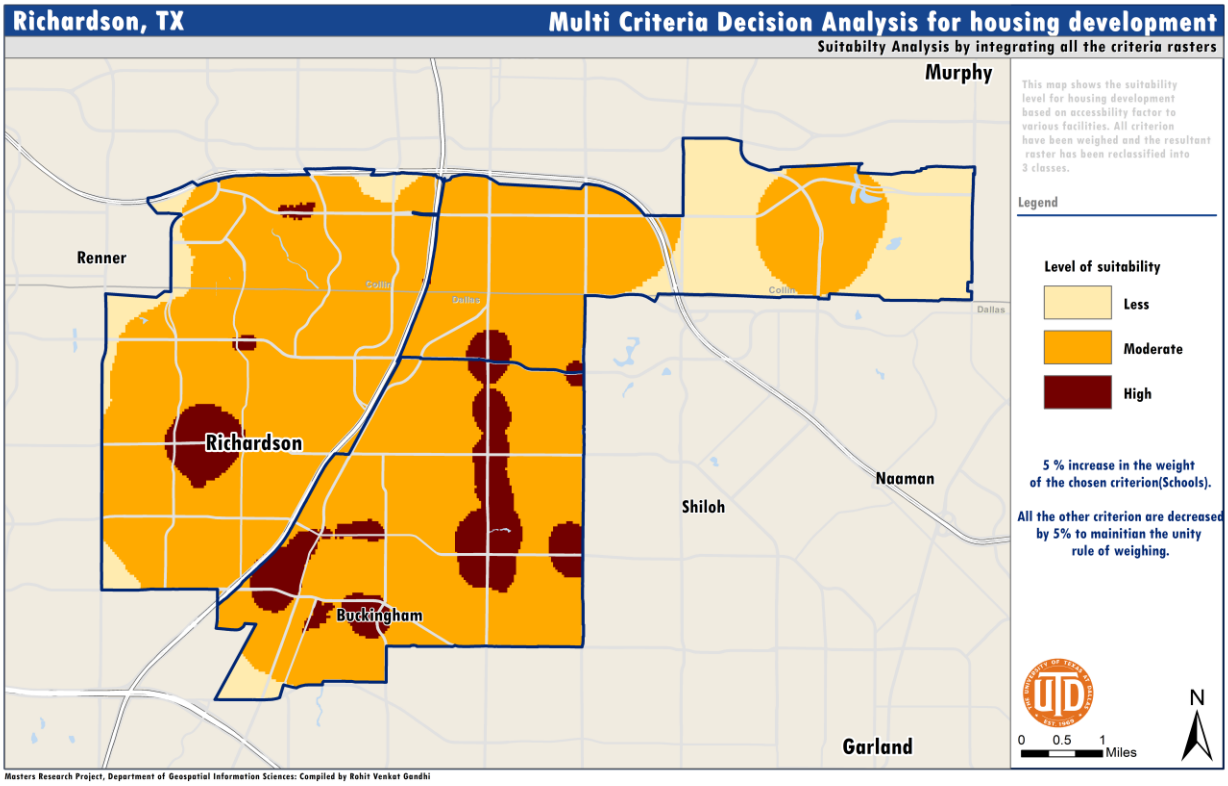

Richardson, TX
Multi Criteria Decision Analysis for housing development
Fire Station Accessibility Analysis
Murphy
Renner
Richardson
Buckingham
Naaman
Shiloh
Garland
The map shows the accessibility of fire stations.
Legend
Fire Stations
Fire Station Accessibility
Value
High: 1
Medium: 0.5
Low : 0
Richardson Boundary
0 0.5 1 Miles
N
Masters Research Project, Department of Geospatial Information Sciences: Compiled by Rohit Venkat Gandhi


Richardson, TX
Multi Criteria Decision Analysis for housing development
Park Facilities Accessibility Analysis
Murphy
Renner
Richardson
Naaman
Shiloh
Garland
The map shows the accessibility to park facilities when selecting sites for housing development.
Legend
Parks
Parks Accessibility
Value
High: 1
Medium: 0.5
Low : 0
Richardson Boundary
0 0.5 1 Miles
N
Masters Research Project, Department of Geospatial Information Sciences: Compiled by Rohit Venkat Gandhi


Richardson, TX
Multi Criteria Decision Analysis for housing development
Educational Facilities Accessibility Analysis
Murphy
Renner
Richardson
Naaman
Shiloh
Buckingham
Garland
Collin
Dallas
The map shows the accessibility to educational facilities when selecting sites for housing development.
Legend
Educational Facilities
Education Accessibility
Value
High: 1
Medium: 0.5
Low : 0
Richardson Boundary
0 0.5 1 Miles
N
Masters Research Project, Department of Geospatial Information Sciences: Compiled by Rohit Venkat Gandhi


Richardson, TX
Multi Criteria Decision Analysis for housing development
Grocery Stores Accessibility Analysis
Murphy
Renner
Richardson
Naaman
Shiloh
Buckingham
Garland
Collin
Dallas
The map shows the accessibility to grocery facilities when selecting sites for housing development.
Legend
Major Grocery Stores
GroceryStores Accessibility
Value
High: 1
Medium: 0.5
Low : 0
Richardson Boundary
0 0.5 1 Miles
N
Masters Research Project, Department of Geospatial Information Sciences: Compiled by Rohit Venkat Gandhi


Richardson, TX
Multi Criteria Decision Analysis for housing development
Suitabilty Analysis by integrating all the criteria rasters
Murphy
Renner
Richardson
Buckingham
Shiloh
Naaman
Garland
This map shows the suitability level for housing development based on accessbility factor to various facilities. All criterion have been weighed and the resultant raster has been reclassified into 3 classes.
Legend
Suitability Analysis
Level of suitability
Less
Moderately
High
0 0.5 1 Miles
N
Masters Research Project, Department of Geospatial Information Sciences: Compiled by Rohit Venkat Gandhi


Richardson, TX
Multi Criteria Decision Analysis for housing development
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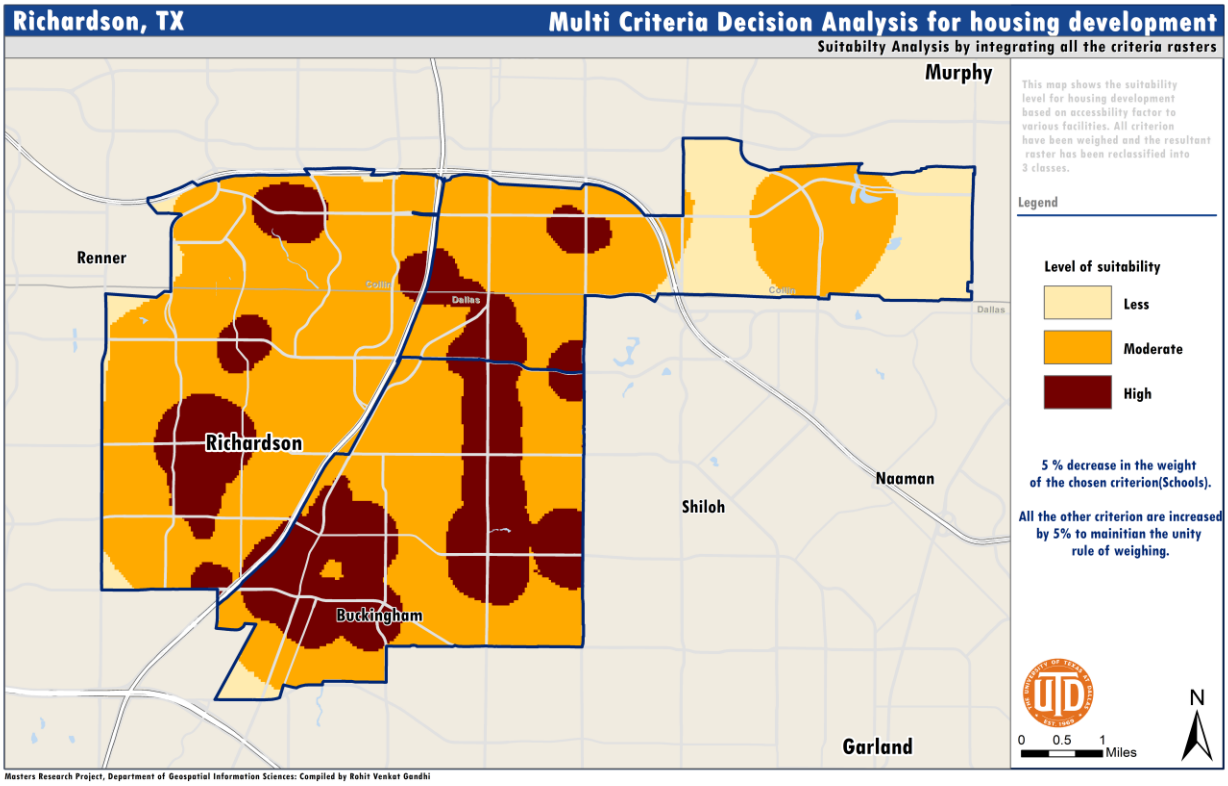
Murphy
Renner
Richardson
Buckingham
Shiloh
Naaman
Garland
This map shows the suitability level for housing development based on accessbility factor to various facilities. All criterion have been weighed and the resultant raster has been reclassified into 3 classes.
Legend
Level of suitability
Less
Moderate
High
5 % increase in the weight of the chosen criterion(Schools).
All the other criterion are decreased by 5% to mainitian the unity rule of weighing.
0 0.5 1 Miles
N
Masters Research Project, Department of Geospatial Information Sciences: Compiled by Rohit Venkat Gandhi


Richardson, TX
Multi Criteria Decision Analysis for housing development
Suitabilty Analysis by integrating all the criteria rasters
Murphy
Renner
Richardson
Buckingham
Shiloh
Naaman
Garland
Collin
Dallas
This map shows the suitability level for housing development based on accessbility factor to various facilities. All criterion have been weighed and the resultant raster has been reclassified into 3 classes.
Legend
Level of suitability
Less
Moderate
High
5 % decrease in the weight of the chosen criterion(Schools).
All the other criterion are increased by 5% to mainitian the unity rule of weighing.
N
0 0.5 1
Miles
Masters Research Project, Department of Geospatial Information Sciences: Compiled by Rohit Venkat Gandhi