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GIS Suitability Analysis to Situate Recreational/Retail Marijuana Stores in Denver, Colorado

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This is to certify that the doctoral study by

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2019

Abstract

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MGIS, University of Calgary, 2009

GIS Graduate Certificate, Algonquin College, 2006

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Professional Administrative Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Abstract

On October 1, 2013, the city of Denver adopted bill CB 570 allowing state-licensed retail marijuana businesses. Section 6-211(b) of the Denver Code of Ordinance codified distance separations between licensed retail marijuana sites and prohibited locations. Using distance decay theory coupled with Geographic Information systems (GIS)-based multicriteria analyses, Denver's licensed retail marijuana stores were evaluated in relation to their proximity compliance with §6-211(b). Using GIS topology testing from 1000 feet to 650 feet, current retail marijuana stores had a compliance percent ranging between 29% to 56% from each other, 2% to 7% from licensed medical marijuana stores, 39% to 68% from childcare centers, and 41% to 70% from schools. Using a 1-sample *t*-test, separation distances of 56 licensed retail marijuana stores were evaluated for compliance. Significant noncompliance was found between sited licensing locations and distance separation requirements [($M = 59.05$, $SD = 145.43$); t (55) = -12.645, $p = 0.000$] illustrating §6-211(b) separation distances are not fully enforced. Using post hoc analysis, GIS-based multicriteria analyses containing suitability factors and constraints revealed 650 feet as an ideal separation distance, bringing currently licensed sites to 93.1% increase rate of regulatory compliance. The implications of this study for social change include offering the city of Denver a proposed distance amendment, which if enacted, would reduce social vulnerability, bring significant compliance to current marijuana retail stores, and provide future guidance for issuing of new retail licenses. These changes offer a sustainable and compliant business growth future with regulatory control.

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Background

Since the legalization of recreational marijuana in Colorado, there have been some concerns regarding the balance between personal rights of recreational marijuana consumers and public health and safety. According to Childs and Hartner (2017), the Colorado model is one of the potential market structures with economic benefits which has a low rating by the balanced score card approach in terms of restricting youth access and ensuring product and public safety. Within the city of Denver's location guide for marijuana facility locations, applicants are permitted to conduct their own zoning research or use the services of external consultants (Denver, 2017). This unguarded implementation of marijuana regulation in Colorado has encouraged an indiscriminate density of retail marijuana stores which are easily accessible to youth and drug treatment patients (Childs & Hartner, 2017). In this new market, the state of Colorado made approximately $200 million in marijuana tax revenue in the 2015-2016 fiscal year, twice the revenue from alcohol sales during the same year (Childs & Hartner, 2017). The spatial distribution of marijuana stores is not subject to legislative policy, thereby resulting in an unregulated market.

There are costs and benefits to the legislation of marijuana in Colorado, but the long-term effects of those costs and benefits are not yet realized. Denver had a 29% increase ($291.5 million to $377.5 million) in recreational marijuana sales and a 3% decrease ($212 million to $206.4 million) in medical marijuana sales from 2016 to 2017 (Denver, 2018c). This is a significant contribution to Denver's financial account which has been used to fund public educational programs (Denver, 2018c). From 2014 to 2018, $11 million of marijuana revenue was used to educate the youth about prosocial choice and healthy lifestyle choices when it comes to using marijuana in Denver (Denver, 2018c). Marijuana legislative policy offers a safe and legal market to its consumers, regulates its sale, and at the same time upholds the public safety and health of the society (Caulkins, Kilmer, & Kleiman, 2016). The cost-benefit view of the use of marijuana presents both threats and opportunities to society. A societal decline due to addictions and other behavioral health is a possible cost aspect of marijuana legislation which may compromise safety at work, social institutions, and public places (Caulkins et al., 2016). In addition, consumption of marijuana makes policing very difficult in terms of keeping roads safe, as impaired drivers under the influence of marijuana may find it difficult to track moving vehicles or respond to a sudden change in bad driving conditions, especially during the winter season (Caulkins et al., 2016).

Development decisions for marijuana retailers are required to protect social vulnerability, limit environment expansion, and boost economic growth. A smart growth initiative is required in situating retail marijuana stores as a development strategy to promote a stronger tax base while preserving preexisting infrastructures within a commercial district (Denver, 2017). The smart growth initiative may save cost, time, and effort that would have been required during the construction of new facilities for marijuana stores.

In the United States, marijuana legalization has undergone significant progress in several individual states. Oregon, Washington, and Colorado are among the few states that have legalized recreational marijuana. Marijuana was legal in Colorado in August 1876 when the state joined the union; however, in 1929 there was legislation to prohibit the sale, distribution, possession, and use of marijuana, classifying violation of all categories as a felony (Johnson, 2015). This was necessary to address the concerns of mass addiction that was impacting public health and safety. In 1937, the Marijuana Tax Act 39 was enacted by the 75th United States Congress to prohibit the use of marijuana at the federal level (Johnson, 2015).

During the 1970s, public opinion had shifted, and some progressive lawmakers were moving forward with legislation which minimized penalties for marijuana possession and use. This led to relegalization efforts and signaled significant progress shifts in favor of marijuana-supporting activists. In 1972, a federal commission report on marijuana and drug abuse from the Nixon administration decriminalized small possession offenses but discouraged heavy consumption (Monte, 2015).

On May 5, 2010, the Colorado legislature passed the medical marijuana bill HB 1284, ushering in the medical marijuana commercialization period (Monte, 2015). When marijuana was legalized for medical purposes, about 4,800 patients enrolled as cardholders, even though licensed medical dispensaries were not operational (Monte, 2015). In 2012, recreational marijuana was legalized in Colorado, and cultivators, retailers, and edible manufacturers were licensed. From 2012 onward, more licensed medical dispensaries and retail stores were opened to satisfy the increasing customer base in Colorado.

There are possible health and safety threats to society regarding the consumption of marijuana. The Colorado Retail Marijuana Code (HB 13-1317) legislation outlined distance separations as regulations to help protect vulnerable populations such as the children and adolescent (Colorado, 2012). These regulations codified licensing requirements for suitable locations to situate recreational marijuana stores.

Problem Statement

One problem of legalized marijuana is the proximity of retailers to vulnerable populations and locations such as schools, recreational centers, childcare establishments, and libraries. To protect vulnerable populations, Section 6-211 of the Denver Code of Ordinance has established distance restrictions of 1,000 feet from vulnerable communities. In practice, this has not occurred. Current recreational licenses in Denver are not in compliance with legislative requirements, probably because applicants are prone to bias or error while conducting their own personal research and investigation (Denver, 2017). Second, situating marijuana store locations is not according to crow flies or Euclidean distance as recommended in recreational marijuana legislation, but a Manhattan distance, which involves horizontal and vertical distances between spatial locations (Wang, 2006). Third, some pre-existing marijuana stores were first in place before the legislation, making it difficult to situate the retail stores according to Denver's legislative requirements.

Marijuana serves a binary purpose: medical and recreational. This calls for rigorous rules and regulations to control its accessibility. Medical marijuana presents some benefits which had to be exploited, enhanced, and shared to treat some diseases such as Alzheimer's, epilepsy, seizures, muscle spasms, Multiple Sclerosis, cancer, Type II diabetes, arthritis, and impotence (Kalant & Porath-Waller, 2016). Both recreational and medical marijuana has provided a total financial revenue of $44.7 million in 2017, with 30% in special sales tax, 12% in state shareback, 10% in licensing fees, 31% in standard retail sales tax, and 17% in standard medical sales tax (Denver, 2018c).

Purpose

The purpose of my study was to evaluate legislative compliance in terms of situating recreational marijuana stores for applicants in Denver using Geographic Information Systems (GIS) technology. GIS describes where things are situated in space and thereby strategically locating new marijuana retail locations within distance restrictions mandated in current marijuana legislation. These distances weakened the relationships between vulnerable populations and marijuana stores through friction of distance. Dempsey (2012) said that strength of relationship between distance and interaction is explained by distance decay theory which states that further the distance between two spatial entities, the weaker the interaction between them, and this phenomenon is based on Tobler's first law of geography. This further implies that the energy and time required to commute serves as a resistance which discouraged potential users. This research study requires a GIS suitability model, a geoprocessing framework to situate optimal locations which are legal spaces within acceptable threshold limits.

Colorado marijuana distribution was enhanced by providing location intelligence through GIS methodology. This project employed an action research strategy intended to situate retail stores in order to not boost business profits but implement licensing requirements, whose main guidelines are focused on providing legal spaces in accordance with public health and safety provisions of recreational marijuana legislation. My action research was applied to evaluate and solve a practical problem that was improved continuously until a suitable solution was feasible. As a GIS practitioner, time was spent in the planning phase to translate legislative requirements into suitability criteria, investigate the research question and proposing possible changes to solve the problem that improved the practice. Observing required comparing analytical results with the present situation to notice any change or response to the action. Reflecting required verifying and critically evaluating analytical results and planning for another cycle of action and modification if further questions arise.

I have developed strong GIS research skills in terms of geoprocessing modeling to interactively design a model and create suitable areas for marijuana stores. My research interest involves social vulnerability and how this relates with administrative policies to create a decision support tool to protect the vulnerable population from behavioral problems such as drug addiction. Using quantitative methods built on factor analysis and an articulated GIS strategy, my research objective is to situate and plot optimal licensed marijuana store locations, taking into consideration codified licensing restrictions and minimizing socially vulnerable residential zoned areas. Using multicriteria evaluation (MCE), I have established several factors or requirements. The model variables are measured as practical distance between hospitals, recreational facilities, parks, religious institutions, schools, community service centers, liquor stores, and medical cannabis stores, mitigating the risk impact associated with the accessibility of marijuana.

Furthermore, the GIS datasets required to generate variables for this model were requested and downloaded from the City of Denver's spatial data repository. My desire is to arrive at a model where the variables and parameters can be changed easily in response to any amended legislation, create a suitability map for Denver, and share this same suitability model and help guide other states as marijuana legalization is codified and enacted. Suitability models can easily accept the integration of external and amended models, paving way for any change for both state and federal legislative provisions in the future.

Nature of the Study

The study involves an investigative and analytical method with a quantitative approach. This was accomplished by building a GIS suitability model with a sequence of steps to solve the spatial problem of identifying potential sites. The GIS suitability approach was taken to identify the suitability of each spatial location and perform exclusive spatial modeling to confirm area coverage required for potential stores. To accomplish the research objective and satisfy the legislative requirements for distance separations and other store requirements like area coverage, input datasets and process modeling are used.

Research Questions

For my initial analysis, I completed an evaluation phase of suitability modeling workflow at the 1000-feet radius codified by Ordinance § 6-211(b). Then, during a post hoc activity, I modeled other distances to evaluate improvement or degradation of compliance. To evaluate a model of ideal distances and achieve ordinance rate compliance, distance separations at 950, 850, 750, 650 feet was tested. Each iteration of multifactor analysis towards legislative compliance brings together action and reflection in pursuit of a practical solution to answer the central research question.

RQ: Using the city of Denver Code of Ordinance § 6-211(b) for situated recreational marijuana stores, are § 6-211(b 1, 2, 3, 4) distance restriction compliance requirements enforced?

The null and alternative hypothesis to be tested for my research question are:

H_0: City of Denver Code of Ordinance § 6-211(b) distance restrictions for situated recreational marijuana stores are enforced.

H_1: City of Denver Code of Ordinance § 6-211(b) distance restrictions for situated recreational marijuana stores are not enforced.

Theoretical Framework

Distance decay phenomenon employed in this research is explained by Waldo Tobler's first law of geography, which is that "everything is related to everything else but near things are more related than distant" (Tobler, 2004, p. 304). My professional administrative study (PAS) project model employed separation distances to establish segregation between the reactional marijuana store and the vulnerable locations. Dempsey (2012) explained that there is a decrease in interaction between two spatial entities with an increase in distance between them. The conceptual framework is designed based on separation distance, a socioeconomic driving force that reduces social vulnerability to access and addiction to recreational marijuana. Separation distances play an important role to mitigate pressure on public health and safety. The nature of the conceptual model offered a framework that was restructured and revised easily based on a suitable distance that will not violate fairness, equity, and social justice in Denver.

Data Sources

The city of Denver has a comprehensive list of spatial open data. I obtained a 2016 aerial photograph of the city of Denver that provided a reference validating the results generated by the model. This ensured that the proposed locations were not on a river or a non-developed area. These spatial datasets served as background for cartography purposes and factors or variables in the suitability model to answer the central research question. The spatial datasets involved point, line and polygon datatypes serving as background datasets involving roads, hydrology, and city boundaries, and GIS model datasets involving land use zoning, childcare facilities, school institutions, and medical marijuana stores.

Plan for Data Acquisition

In my study, project needs were met through high-quality datasets already available in the city of Denver data portal. The validity and reliability of these spatial data are assured and were controlled through careful map projections to align all data layers. After data were collected and the significant GIS data layers derived, spatial data values were transformed, weighted, and combined to locate the suitable areas. The data portal was visited and consent was given to download a comprehensive list of the input datasets.

Timeline for Completion

The envisioned timeline to complete the PAS spanned across four consecutive quarters at Walden University. Upon approval from my committee and the Program

Director, I began official consultation with the Denver Office of Marijuana Policy to gather data in both spatial and nonspatial formats. I spent the next 4 weeks writing my literature review with the help of a Walden University librarian. After all research data had been collected, I reconditioned the datasets for another 4 weeks, establishing the correct field type, data format, spatial coordinate system, and geocoding to serve the purpose of the analysis with an extended version of ArcGIS Info software. In addition, a period of 2 weeks was needed to handle suitability analysis required for the research methodology section. A final PAS report after research findings and results verifications was created and submitted to the PAS committee.

Significance of the Study

My study bridged and closed research gaps involving social vulnerability of the population and noncompliance to legislative requirements by providing an administrative framework to conduct a suitability analysis of marijuana stores in Denver. This was accompanied by limiting access to the vulnerable population by situating marijuana stores in locations that were located far from these target populations. Furthermore, these restrictive distances used in the suitability model are subject to any legislative change according to Colorado recreational marijuana location requirements.

Summary and Conclusion

My study offered recommendations to reduce societal damage and enhance risk mitigation. Ignoring the negative risk of recreational marijuana use could lead to increased vulnerability and failure of social norms in Denver. My study will reduce and mitigated risks to public health and safety while still offering benefits to the administration in terms of business taxes and reducing social vulnerability in Denver.

Section 2: Conceptual Approach and Background

Introduction

This section is focused on the literature review regarding the locational effect of marijuana stores on the Denver public. In this section, the review starts with a brief description of marijuana, its evolution, costs and benefits, present legislation, location requirements, and what the future holds regarding accessibility of recreational marijuana in Denver. Colorado and Washington were the first states to secure marijuana legalization for recreational purposes on November 6, 2012. The shift from illegality to medicinal and later recreational use has underscored how important the topic of marijuana is in the city of Denver, Colorado. I also discussed the theoretical framework and GIS suitability analysis to situate marijuana stores strictly according to legislative requirements.

Location, distance, and compliance are the focus of the review to reduce the risk of social vulnerability while upholding public health and safety in Denver. The difference between location and distance is that location is position on a surface; distance represents how far away or how close two locations can be from each other. Parker, Kuuttiniemi, Klaasen and Hill (2000) described compliance as the state of being in accordance with specific guidelines and regulations which defines standards and quality of public goods and services. Location, distance, and compliance of recreational marijuana stores are needed in this research to mitigate vulnerability risks towards vulnerable populations' health and safety. Mandal (2012) emphasized that there is an increased likelihood of trying other illicit drugs after using marijuana.

Strategic Search of Literature

This section is an overview of the electronic search methods adopted to search relevant literature from scholarly databases for the purpose of review. I focused on subject-specific databases such as ScienceDirect, Taylor and Francis Online, SAGE Journals, Political Science Complete, PsycARTICLES, LegalTrac, Nexis Uni, PubMed, PsycINFO, and ProQuest searching for articles published between 2015 and 2019 to ensure timeliness of publication. The search terms were *geographic information systems*, *GIS*, *suitability analysis*, *distance decay*, *proximity and distance*, *legislative compliance*, *Tobler first law of geography*, *marijuana*, *THC*, *cannabis*, *social vulnerability*, *public safety*, *public health*, *schools*, *risk*, *Denver*, and *Colorado*. Online articles, legislative documents, and other city of Denver policy guidelines were searched and downloaded from Denver web portals.

Marijuana is the dried leaves and flower sections (buds) of an ancient plant called Cannabis sativa (Caulkins et al., 2016). The flowers and leaves contain chemicals called delta-0 tetrahydrocannabinol (THC), a psychoactive ingredient that causes intoxicating effects and alters the mood of a person (Caulkins et al., 2016). The sensation of being under the influence of marijuana or feeling high leads to some effects such as impaired short-term memory, improved appetite for foods, and suppressed nausea. Marijuana is usually consumed in several forms such as blunts (hollowed cigar filled with marijuana and wrapped with a tobacco leaf), joints (marijuana cigarette), and edibles (marijuana-infused cookies, candies, drinks, beer, and chocolate bars; Caulkins et al., 2016, p. 11). Smoking marijuana requires the use of water pipes, cigarette papers, and bongs, while vaping requires an electric vaporizer to inhale heated marijuana. These products are sold as legalized marijuana products in marijuana stores to adults only.

Theories, Concepts, and Models

The Distance Decay Theory

Distance decay theory involves a negative relationship between distance and familiarity. The distance decay theory describes the effect of distance on spatial interaction, spatial dependence, or relationships in terms of human geography (Dempsey, 2012). The further the distance between two locations, the weaker the interaction and more isolated the locations will be from each other (Dempsey, 2012). The theory is based upon the concept of the friction of distance where distance hinders the interaction between places (Dempsey, 2012). Figure 1 offers a graphic representation of the distance decay phenomenon.

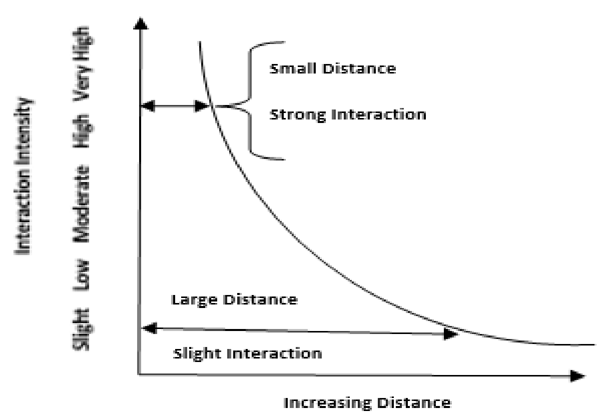

Figure 1. Distance decay phenomenon.

An example of the distance decay phenomenon is the distance or range between a cell tower and a mobile device such as a cell phone. An increased distance diminishes coverage or service. Similarly, for marijuana stores, increased distance makes the recreational marijuana stores less noticeable to vulnerable groups. Physical proximity to marijuana stores brings familiarity, which later induces attractiveness and possible visits to the store. Subsequently, if proximity increases attraction, then remoteness should increase repulsion, which supports the research purpose.

My PAS examined locational requirements for situating retail stores and its effect on separation distance. Distance is a common term used to describe proximity or remoteness of an object from another object. There are several types of distance, but my research is focused on Euclidean distance which assumes that the square of the hypotenuse that is opposite of the right angle (90 degrees) is equal to the sum of the squares of the other two sides in a triangle. Fotheringham et al. (2007) further described Euclidean distance as a straight line distance between two location coordinates (x_1, y_1), and (x_2,y_2) in a two-dimensional plane and this distance ($d_{1,2}$) is represented by Figure 2:$d_{1,2}$ = sqrt (($x_2 - x_1$)**^{2} + ($y_2 - y_1$)**^{2})

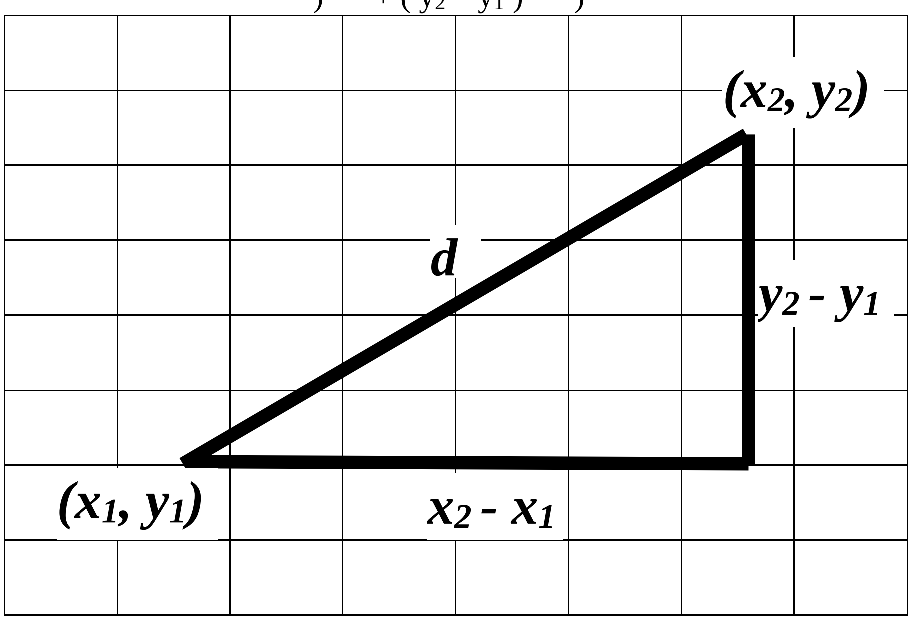

Figure 2. Euclidean distance on a two-dimensional plane.

Euclidean distance is also a good measure of spatial separation. Euclidean distance ignores any obstacles such as buildings or water features (Fotheringham et al., 2007). Euclidean distance is always the shortest measurement of distance when compared to route distance between the same two locations.

Tobler's First Law of Geography

Waldo Tobler's first law theory offers the same foundational approach as the distance decay theory, which is a core concept of the research problem. Waldo Tobler's first law of geography states that "Everything is related to everything else but near things are more related than distant" (Tobler, 2004, p. 304). This means that when things are distant, they are disconnected and unrelated. This law constitutes one of the foundational concepts toward spatial analysis and modeling. Sui (2004) mentioned that the first part of the Waldo Tobler's first law denotes the relationship between all things in geographic space and this is attributed to spatial dependence. The location of one spatial element in geographic space is dependent on another observational location in space. Sui (2004) further explained the second part of Waldo Tobler's first law describes how distance determines the degree of variation in the relationship between locational observation and this is attributed to spatial heterogeneity. One of the research purposes assumed a spatial heterogeneity standpoint, a property of a spatial process to establish more variation and reduce dependence on each other.

Near objects are defined by diminishing distance which makes a stronger positive relationship between locations. Distant things are known for weakening relationships because of the absence or invisibility of one towards the other. This is synonymous in the idiomatic expression “out of sight, out of mind” which means that it is easy to forget something that cannot be seen. Since the world is orderly with respect to space, Miller (2004) argued that there is varying intensity in the spatial associations, with near things more flexible and related than distant objects in geographic space. Traveling to distant locations cost more in time and resources than near locations, thereby causing a loss in interest regarding making a trip. Increased distance is synonymous with the increased cost of travel and out of sight characteristics that will discourage vulnerable groups. For instance, legislative compliance of recreational marijuana is ensured with an ‘out of sight’ philosophy, employed in Fort Collins through the application of distance buffers from schools, to keep marijuana away from children and teenagers (Goddeeris & Fricke, 2018).

Caincross (1997) emphasized the death of distance through efficient ways of communication and transportation can lead to a shrinking world. In most societies, offenders are usually punished by separating them with a designated distance from the entire population. In other words, these offenders are being banished because of their high-risk personalities which are detrimental to public safety.

GIS Suitability Model

The GIS suitability model represented the conceptual framework of my study to resolve the challenge of legislative compliance of distance and suitable store locations. This action research employed a quantitative approach to bridge the gap in practice by strategically situating suitable locations, thereby ensuring compliance to marijuana legislative requirements in Denver. The research process was designed to offer an improvement to the proximity situation which is not in conformity with the legislative requirements. My research process was also a recursive practice through observation and further evaluation until the best locations are sited with a high compliance rate (Rudestam & Newton, 2015). With a clear understanding of the research problem, the entangled webs of causality and complexity were adjusted and solved incrementally using the conceptual framework shown in Figure 3.

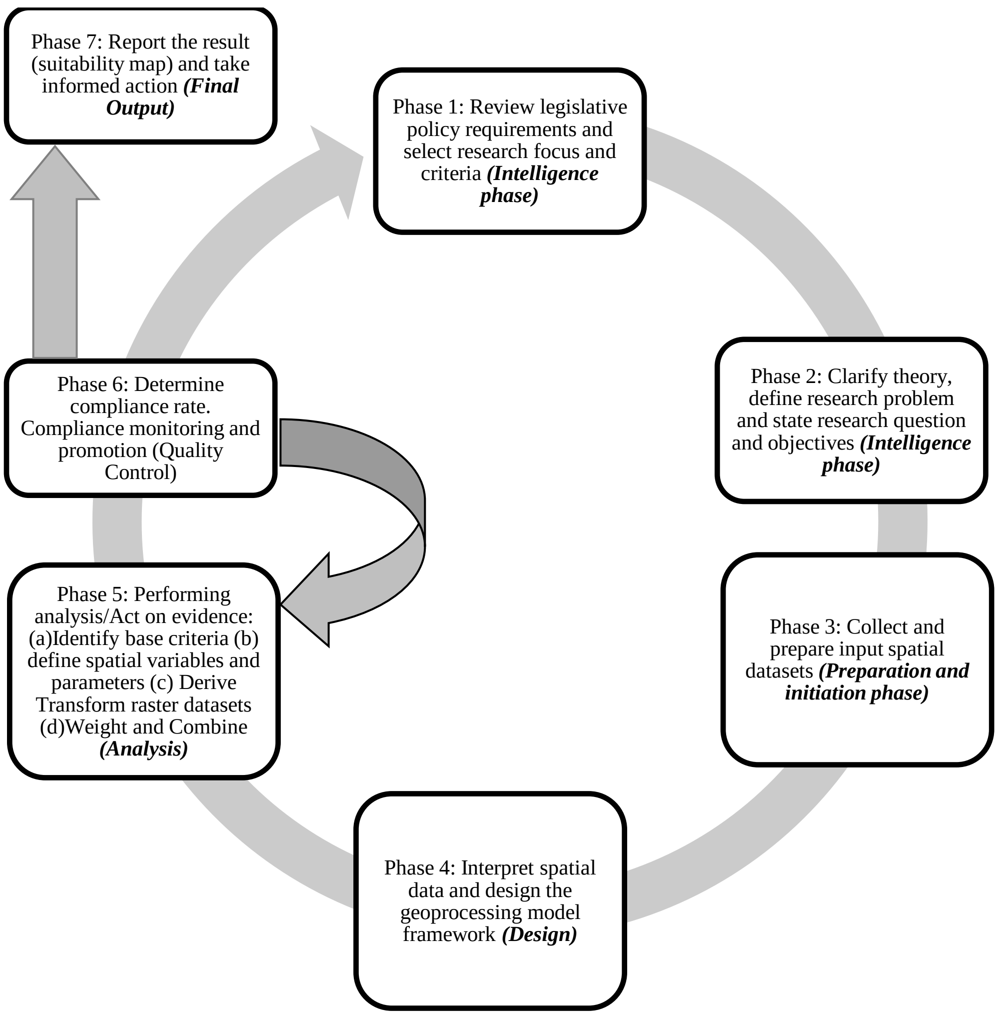

Figure 3. GIS suitability model.

The research problem presented an undesirable situation of social vulnerability in Denver. Marijuana legislation has provided distance restriction guidelines to eliminate the problem of non-compliance. The marijuana policy aimed to reduce the likelihood that members of vulnerable groups will have access to marijuana dispensaries by locating these places away from the vulnerable communities. The success of this policy depends largely (but not solely) on ensuring compliance with the zoning laws. These legislative requirements was applied as both suitability factors and constraints (marijuana legislative and environmental constraints) to solve the spatial problem in a GIS process model referred to as a suitability model. A suitability model is used during most multi-criteria evaluation (MCE) to determine the appropriateness of a given area for a dedicated purpose or use (Chan, 2017). Multi-criteria evaluation can be described as the application of weighted overlay function to combine multiple GIS rasters (factors and constraints) using their individual weights or percentage of influence that must not exceed 100 percent (Caradima, 2015). Multi-criteria evaluation served as an analytical tool that provides significant information to answer the research question of providing a compliance rate to the recreational marijuana legislation, based on multiple factors and constraints.

Relevance to Public Organization

Compliance Rates with Legislative Requirements

Credible compliance is measured by how much the applicable laws and guidance are obeyed and a violation of such laws in a community could lead to penalties, fines, and imprisonment (Parker et al., 2000). A high rate of compliance by the marijuana business establishes a good reputation among store owners and sets a good standard for other states seeking to adopt similar legislation. The legislative requirements are established to control the density of recreational marijuana stores, thereby reducing the social vulnerability and illegal conduct associated with non-compliance (Parker et al., 2000). To improve conformance, the present legislative requirements on distance restrictions to situate retail stores can be amended to strengthen the existing framework and further enforce future compliance.

Compliance to recreational marijuana legislation must be credible and effective by identifying the boundaries of permissible conduct within the marijuana retailing business (Competition Bureau Canada, 2015). From a sociolegal perspective, compliance is the state of conformity with regulations in a society (Amodu, 2008). Conformity with marijuana regulation is necessary to promote adherence in a marijuana business community in Denver, Colorado.

A commitment to legislative conformance is required to control and reduce the emergence of illegal business stores prior to the siting of these businesses (Cleveland, Simon, & Block, 2018). This mitigates the cost of non-compliance that can expose a marijuana business to fines and other administrative penalties, thereby compromising the reputation of the market (Competition Bureau Canada, 2015). The sensitive nature of recreational marijuana business demands an independent compliance program to monitor the compliance rate.

The earlier compliance programs are implemented, the quicker present and future violations of recreational marijuana legislation can be detected and avoided (Competition

Bureau Canada, 2015). Addressing deficiencies earlier in a given system is less expensive than later in the developmental cycle. The compliance program must be well-structured with a good framework to ensure a credible recreational marijuana business that is not exposed to a breach of the legislative Act and detrimental to public health and safety (Eadie et al., 2016). At several distance intervals, Valiente et al. (2018) used GIS tools to evaluate compliance which resulted in some tobacco stores failing to meet the regulation threshold. With the PAS framework, the restrictive distance requirement of 1000 feet within the recreational marijuana legislation were used and subsequent distance intervals were also considered to extend the regulation threshold.

Restructuring is needed to offer leniency to retailers who will be in violation of keeping the locational requirements and have flouted the required regulations (Fry et al., 2016). Restructuring the marijuana business framework demands a form of leniency to evaluate and promote adherence to a new compliance requirement and fostering a culture of compliance henceforth (Competition Bureau Canada, 2015). This extent of leniency is determined by the acceptable distance prescribed during suitability analysis to safeguard the reputation of a recreational marijuana business and improve compliance in the future. In this research, distance is the sole determinant of compliance that served as the acceptable parameter for achieving an effective compliance behavior among recreational marijuana store owners.

The handling of compliance breach in this research involved the identification of non-compliance areas thereby strengthening the compliance behavior among regulated parties (Eadie et al., 2016). According to Amodu (2008), there is little chance of ensuring perfect compliance to any policy. This defines the extent to which marijuana stores comply with regulatory standards within the recreational marijuana legislation. Since most regulatory processes are subject to change, this fluidity can be taken advantage of, to seek an increasing compliance rate until a reasonable percentage rate is established to enhance compliance behavior (Amodu, 2008). This persuasive or bargaining strategy is accommodative enough to offer leniency to initial violators through compliance rather than retribution. Compliance can be viewed as a process-based strategy implemented to improve and secure a moral dimension to a regulatory breach of existing violations, reduce accessibility to vulnerable groups and prevent future recurrence (Pearson, Deen, Wilson, Cobiac, & Blakely, 2014).

For instance, Edison, a town in Alberta, decided to adjust its legislative distance for situating separation of cannabis dispensaries from 100 meters, as recommended by the provincial government, to 200 meters, a new distance proposed in the Edson Cannabis framework to promote public health and safety (Edson, 2018). Without compliance, legislation is ineffective especially when it has to do with public health and safety. Moore (2018) acknowledged that the amended marijuana legalization in Edson is more restrictive and severely curtailed where marijuana retail shops would be situated.

In a tobacco retailing study, Valiente et al. (2018) evaluated compliance with separation distances between tobacco stores and schools, and thereby conclude that the more restrictive regulations are to constrain the distribution of tobacco retailers, the better the compliance rate. Valiente et al. (2018) emphasized the important role of GIS tools such as the proximity toolset which offers straight distance separations used in the comparison phase to reveal locational compromises within the study. A similar strategy can be employed to evaluate a compliance rate within the regulatory cycle that can be recommended to enforce stricter recreational marijuana policies. Compliance rate can be evaluated with regulatory requirements which are viewed as factors and constraints in the GIS suitability model. Enforcing compliance demands conducting conformance tests, control, and promotion within a regulatory cycle of legislation to establish modifications to existing policy. The compliance rate can be computed as shown in equation 2 below.

Compliance rate in % = (number of complying recreational marijuana stores / total number of recreational marijuana stores) *100 (2)

Where the number of complying recreational marijuana stores are suitable stores based on a constraint distance, and the total number of recreational marijuana stores are the active recreational marijuana stores present in Denver.

Organization Background and Context

Evolution of Recreational Marijuana Legalization

Colorado's legislative timeline towards the legalization of recreational marijuana is outlined here (SDRG, 2016):

- 1975: Colorado Legislative decriminalized minimal offense of marijuana possession up to 1 ounce with a US$100 fine.
- 1979: First medical marijuana bill signed into law in Colorado State.
- 1981: Second medical marijuana bill signed requesting the patient to get permission for use from the federal government.

- 1998: Amendment 19 is denied first attempt to put medical marijuana on the ballot.
- 2000: Amendment 20 is approved at its second attempt by Colorado voters, thereby legalizing and allowing the use of medical marijuana.
- 2006: Amendment 44 failed at ballot regarding legalizing possession of up to 1 ounce of recreational marijuana by adults above 21 years of age.
- 2007: Denver District court rules, allowing for the opening of large medical marijuana dispensaries.
- 2010: Licencing and regulation of Medical marijuana dispensaries are approved in the Colorado Medical Marijuana code by the Colorado Legislature.
- 2012: Amendment 64 is passed by the Colorado voters, decriminalizing adult possession of recreational marijuana and proposing a regulated retail system.
- 2013: City council adopted the Retail Marijuana Code, licensing and regulating ordinances, adding a 10% sales tax to retail marijuana and a 15% excise tax.
- 2014: First waves of recreational marijuana retail stores are opened in Denver.

Denver voters approved designated recreational marijuana store locations based on the following requirements stated in Sec. 6-211 of the Denver Code of Ordinance states which states that every recreational marijuana store must be 1000 feet or 304.8 meters away from the parcel line of the following:

- All schools
- Child care centers or homes

In addition, every recreational marijuana store must be 1000 feet or 304.8 meters away from the nearest building edge or the centroid of the building of the following:

- Medical marijuana centers
- Other recreational marijuana stores

Finally, every recreational marijuana store must be redesignated for commercial land use.

Marijuana Market Models

The use of marijuana is a controversial topic due to the risk it presents to the community. These risks are viewed as negative (cost) and positive (benefits), serving as a double-edged sword with public health and safety issues, and medical and financial benefits. Marijuana has a negative effect on the brain that could negatively impact human memory, reduce concentration, impair thinking, decision-making abilities, and cause lung infection diseases (Kalant & Porath-Waller, 2016). Marijuana use causes a second-hand effect to non-marijuana smokers in proximity and non-marijuana smokers invloved in an accident can be wrongly accused due to the presence of THC in the body fluid during a test for intoxication (Caulkins et al., 2016). Unlike alcohol, marijuana metabolites remain a few days in the human body long after consumption, thereby compromising the present state of a users' consciousness (Caulkins et al., 2016). This also calls for more distance separations for store location as well as consumption areas.

Valiente et al. (2018) evaluated the compliance of tobacco stores in a GIS study, where restrictive distances intervals to schools were examined to decrease tobacco retail availability. In their GIS study, Valiente et al. (2018) mentioned that 5.3% (34 out of 634 tobacco stores) complied within 150 meters of each other, thereby providing useful insights towards the geographic distribution of these tobacco retail stores. Controlling the distribution of these tobacco stores through minimum distances is essential to restricting youth access which serves as one of the factors of a good marijuana market model. Gosselt, Hoof, and Jong (2012) emphasized the importance of compliance in respect to legal age limits to limit the sales and availability of alcohol to adolescents. Additionally, Childs and Hartner (2017) mentioned three potential market structures covering distribution and retail of recreational marijuana. These three markets models are the state-owned monopoly, Colorado model, and the Borland model.

The State-owned Monopoly Model

Within the state-owned monopoly structure, both distribution and sale of recreational marijuana are operated and controlled by the government. An example of the state-owned monopoly is the market structure adopted by Canada's Ontario, New Brunswick and Quebec provincial governments. Childs and Hartner (2017) mentioned that the improvement of safety standards surrounding marijuana consumption is the responsibility of the state. The interference of the government regulations is in place by enforcing strict rules on the producer, distributor and retail level of the business. These rules are moderate to a considerate level, but they still curb illegal markets that ignore the regulations, age limits and other consumption standards.

Colorado Model

The Colorado model has very light regulations concerning restricting youth access to cannabis use as well as product safety (Childs & Hartner, 2017). The light regulations are in existence since applicants are allowed to conduct their own research and investigation regarding situating store locations (Denver, 2017). This model is controlled by private retailers making it difficult to monitor for regulatory compliance (Denver, 2017). Even though there are economic gains in this model due to free market competition, health and product safety is a concern evident in drug addictive behavior in Colorado (Childs & Hartner, 2017). This model is the primary reason for my PAS research to offer a more suitable model to site recreational marijuana stores, thereby restricting youth access and potentially reducing social vulnerability.

Borland Model

During Washington State's 2005 tobacco regulation Borland ushered in a licensing model (Borland model) to limit the number of private retail locations which are supplied by a single distributor. The Borland model adopted for the marijuana market is also efficient in the restriction of youth access to marijuana and to curb the illegal market that could compromise product quality. Childs and Hartner (2017) indicated that the Borland model offers high youth restriction, more economic benefits, and a guarantee for product safety. Childs and Hartner (2017) also indicated that the Borland model restricts youth access better than the Colorado model which were revised in the light of this PAS study. Table 1 illustrates how models are measured and scored.

Table 1

Marijuana Market Models

	State-owned Monopoly	Colorado Model	Borland Model
Restricting Youth Access	Moderate	Low	Moderate to High
Ensuring Product Safety	Moderate	Low	High
Capturing Economic Benefits	Moderate	Moderate to High	High
Reducing Non-monetary costs	Moderate to High	Low	Moderate

Role of the Researcher

As a GIS analyst, I chose carefully the GIS model techniques to optimize the suitability result. Even though the vector analysis approach can be used in some suitability models due to its less processing time and disk space, my preference was to conduct the suitability analysis by first converting all vector data to raster formats. The MCA which constitutes managing, combining, aggregating and disaggregating requires many input data layers to be in raster format. The raster format requirement is necessary in accomplishing complex spatial analysis and overlay very quickly by evaluating raster cells from multiple raster layers representing the same location. Raster analysis is also preferred due to the accessibility of a raster calculator that can easily compute complex mathematical expression in a suitability model.

I used 30 meters cell size as the model requirement that assured the quality of the result, thereby balancing geo-processing speed and size of resulting raster datasets. A smaller cell size, such as 5 meters, might crash the computer or slow down its speed while a larger cell size will negatively affect the analytical result in terms of quality. Each iterative approach within the suitability model were applied and monitored based on separation distances until an excellent compliance rate was attained. I also ensured that building and parcel polygons were used as recommended in the Denver's licensing requirement for situating retail marijuana stores.

Summary and Conclusion

The literature under review offered more insights into the evolution of recreational marijuana legislation, its present legislative requirements in practice and recommendations to improve the quality of compliance in Denver. The use of GIS offered a platform to investigate and analyze spatial factors and constraints in MCE to deduce optimal locations that can be recommended for conformance. I evaluated the regulatory compliance for distance separation of licensed recreational marijuana stores. With evidence of non-compliance, recreational marijuana legislation can be amended and improved using the comparison of patterns and insights using a data-driven decision-making process.

Section 3: Data Collection Process and Analysis

Introduction

I employed the GIS methodological framework to evaluate legislative compliance by identifying stores closer than 1000 feet (304.8 meters) through proximity analysis to examine whether they exceed the legislative threshold. The application of the analytical hierarchical process (AHP), a multi-criteria decision-making method under MCE integrated all suitability factors to further solve the research problem involving proximity of retail marijuana stores with vulnerable locations. This section examined sources of evidence, operational research data, GIS proximity, and suitability analysis used in examining compliance rates within each cycle of analytical evaluation.

Practice-focused Questions

The following research question was evaluated to resolve the research problem of proximity of recreational marijuana store to vulnerable locations:

RQ: Using the city of Denver Code of Ordinance § 6-211(b) for recreational marijuana stores, are § 6-211(c 1, 2, 3, 4) distance restriction compliance requirements enforced?

The null and alternative hypotheses were as follows:

H_0: City of Denver Code of Ordinance § 6-211(b) distance restrictions are enforced.

H_1: City of Denver Code of Ordinance § 6-211(b) distance restrictions in § 6-211(c 1, 2, 3, 4) for situated recreational marijuana stores are not enforced.

The purpose was to increase the legislative compliance of retail marijuana stores. This can be accomplished by recommending an acceptable separation distance between the stores and away from vulnerable locations. These distances can be enforced thereafter to solve the problem of noncompliant stores disproportionately situated in Denver.

Sources of Evidence

Data Collection and Preparation

Secondary data sources can be described as data repositories where preexisting information is acquired and stored as observational data by research or government agencies (Hay, 2016). The use of secondary data collected for bureaucratic purposes can also play an important role in providing insights during the research process. During data analysis, the secondary data revealed spatial patterns required to investigate violated retail marijuana stores and situate new stores.

Data Source

Secondary data are mostly collected by government agencies, universities, and research institutions. The city of Denver served as the primary source of operational data. Presently, the city of Denver provides a total of 229 archival datasets all maintained in an open data catalog by the city’s Technology Services and Enterprise Data Management department. These datasets must be original and current to provide credence, validity, and quality to research findings. Secondary data were easy to use and less time-consuming in terms of acquisition, reducing the project completion timeline as well as associated project costs. Consent from the dataset holder was also obtained.

Secondary data required for the PAS are public records available on demand from the city of Denver data portal using the Freedom of Information Act (FOIA), which was filed and submitted after Walden Institutional Review Board (IRB) approval was received. When it comes to recreational marijuana acquisition, the city of Denver remained the best data source. The aid of city staff saved time and cost of data acquisition and helped in the evaluation and improvement process towards data preparation for the GIS suitability analysis.

Data Accuracy

Both spatial and attribute accuracy are ensured to eliminate error and bias. Most spatial data inaccuracies arise from scale effects and wrong map projections which negatively impact location mapping with respect to the true location of spatial features. The map scale was set to 1:54,000 which means that a map unit represent 54,000 units of the earth's surface. A cell size of 30 meters was also employed to acquire a good level of detail and spatial resolution, reducing file sizes and the geoprocessing time required to execute the suitability model.

Metadata

Metadata are described as the data about geospatial data. Metadata provides information on data coverage, date of acquisition, data description, format, quality, currency, ownership, and organizational rules regarding data transfer (Chang, 2006). The metadata were based on Federal Geographic Data Committee (FGDC) standards which were adopted by federal agencies to share descriptive information about public data. FGDC coordinates the metadata of geospatial data standards established during the data production process to inform about the data currency, quality and area coverage (Chang, 2006). The city of Denver's data portal served as an important source of GIS metadata as well as metadata information accessible in ArcMap or ArcCatalog software application.

Spatial Reference (Projection and Datum)

Chang (2006) described map projection as the process of transforming the spherical earth surface to a flat surface. A spatial reference of North American Datums (NAD) 1983 High Accuracy Reference Network (HARN) State Plane Colorado Central Federal Information Processing Standard (FIPS) 0502, as shown as in Table 2 is recommended for all datasets to avoid positional errors during geospatial analysis. This spatial reference adopted the Lambert Conformal Conic map projection parameter that is also used by equidistant conic projection to preserve distances between two standard parallels.

Table 2

Map Projection

Geographic Coordinate System	Map Projection
GCS_North_American_1983_HARN Angular Unit: Degree (0.0174532925199433) Prime Meridian: Greenwich (0.0) Datum: D_North_American_1983_HARN Spheroid: GRS_1980 Semimajor Axis: 6378137.0 Semiminor Axis: 6356752.314140356 Inverse Flattening: 298.257222101	NAD_1983_HARN_StatePlane_Colorado_Central_FIPS_0502_Feet WKID: 2877 Authority: EPSG Projection: Lambert_Conformal_Conic False_Easting: 3000000.000316083 False_Northing: 999999.999996 Central_Meridian: -105.5 Standard_Parallel_1: 38.45 Standard_Parallel_2: 39.75 Latitude_Of_Origin: 37.83333333333334 Linear Unit: Foot_US (0.3048006096012192)

Geocoding

Chang (2006) identified the geocoding process as linear interpolation which involves the generation or approximation of new address values based on an existing set of address values within a secondary datsset. Secondary data for recreational marijuana locations were available in a spreadsheet format within the Denver data portal. Address locations in an Excel spreadsheet required geocoding to create spatial features in a GIS environment. The geocoding process required two set of datasets to create a point feature dataset for subsequent analysis. First, a street network (roads) was used as a reference dataset consisting of attributes such as address range on either side of street segment, street name, street type, ZIP codes and direction. Second, an address table contained a list of recreational marijuana business names, business license numbers, and full addresses.

ArcGIS geocoding engine used the address locator as shown in Figure 4 to initiate the process of address matching by locating the street segment in the street network dataset, interpolating where an address record within the address table falls within the address range on a street segment (ESRI 2019). A second round of spatial query was conducted to ensure that all address points completely fall within their corresponding parcel. If outliers exist, they must be moved and placed within the designated building outline and parcel boundary. As recommended in the CO Code of ordinance (Denver, 2018b), the separation distances are measured from the building or parcel boundary lines and not from the address point.

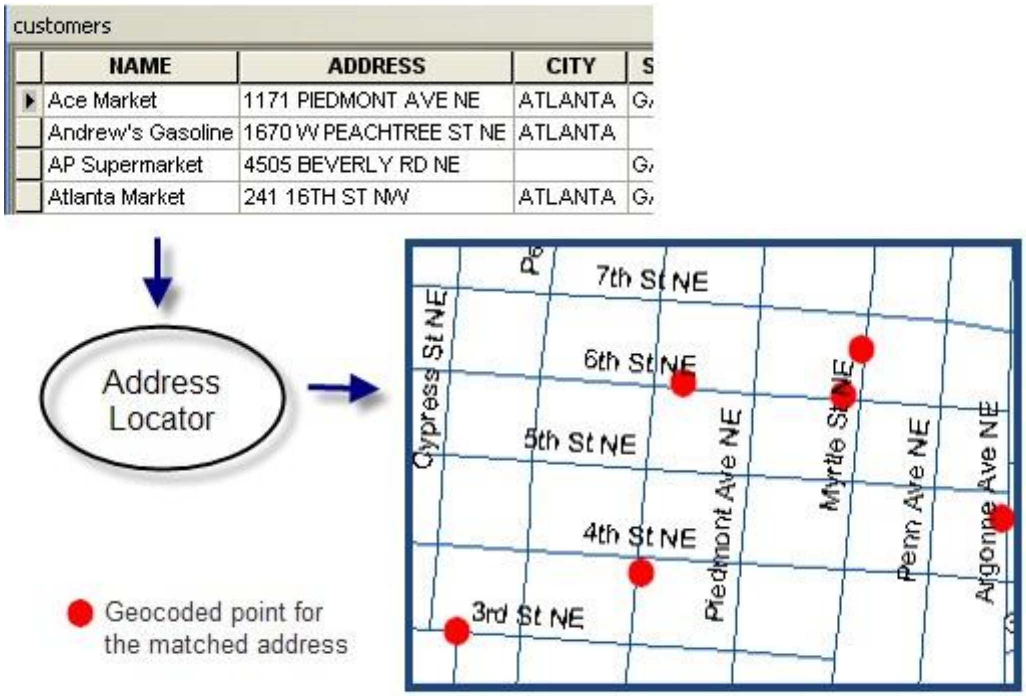

Figure 4. Linear interpolation for address geocoding.

Published Outcomes and Research

Figure 5 shows the GIS modelling steps required to accomplish the research process and outcome in one suitability cycle and proceeds to the next cycle if the compliance rate should be increased.

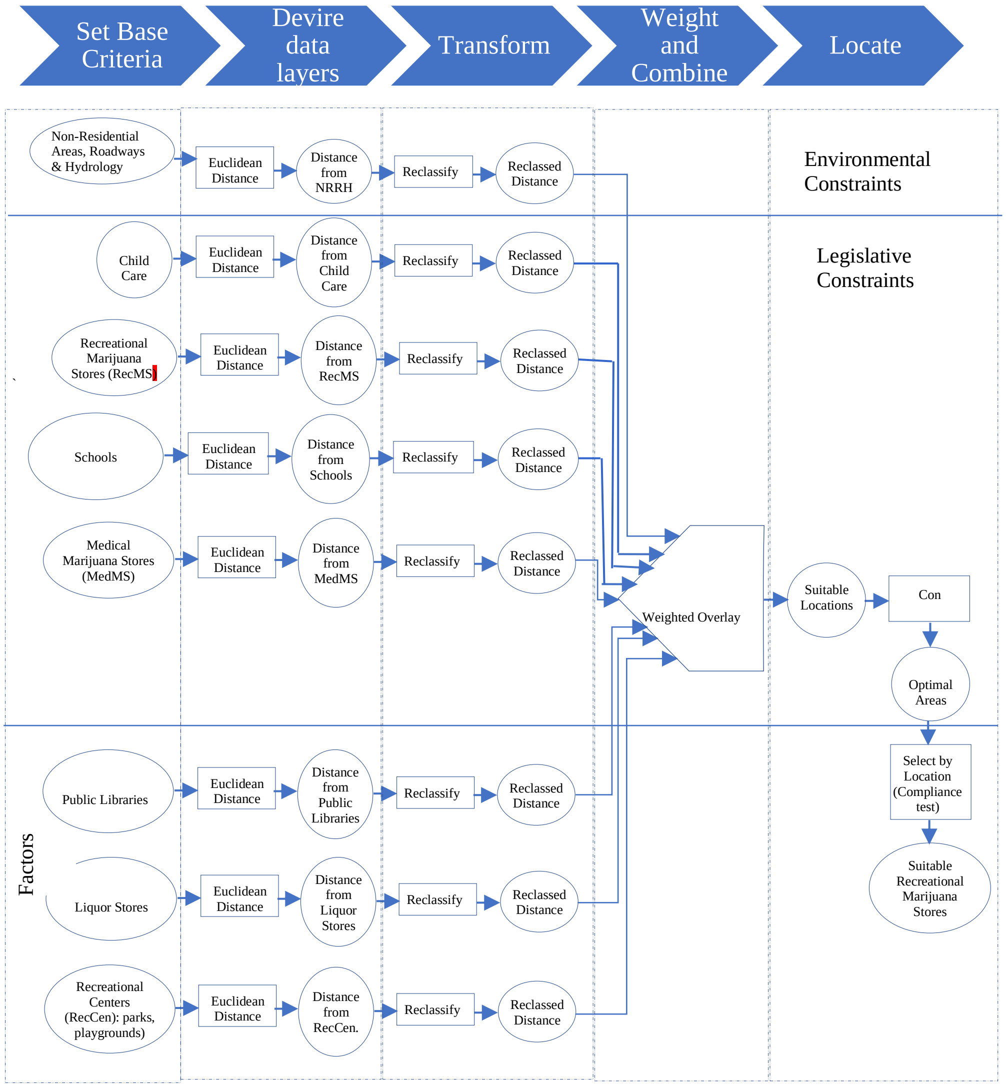

Figure 5. Suitability modelling steps in GIS.

Archival and Operational Data

Data Inventory

Within the Denver open data catalog at https://www.denvergov.org/opendata, I downloaded spatial datasets in shapefile formats and non-spatial datasets in ‘csv’ format. I also downloaded a 2016 aerial photography of the city of Denver, required to provide visualization and ground truth reference for validating the results generated by the suitability model (Denver, 2018). The envisioned datasets were grouped as background and analytical datasets. The map of the city limits and its highways were the background layers shown in the Figure 6 below.

Background datasets

Figure 6 shows a map containing the base layers which provide the background setting for the map. These base layers consist of the City Limits, terrain, and major highways. They are all maintained by the City and County of Denver, Technology Services / Enterprise Data Management.

- City Limits: This is a spatial representation of the city's jurisdictional boundary line which defines the areal extent of the city of Denver's border line.
- Highways: This is a spatial representation of the freeways within the city of Denver's street network.

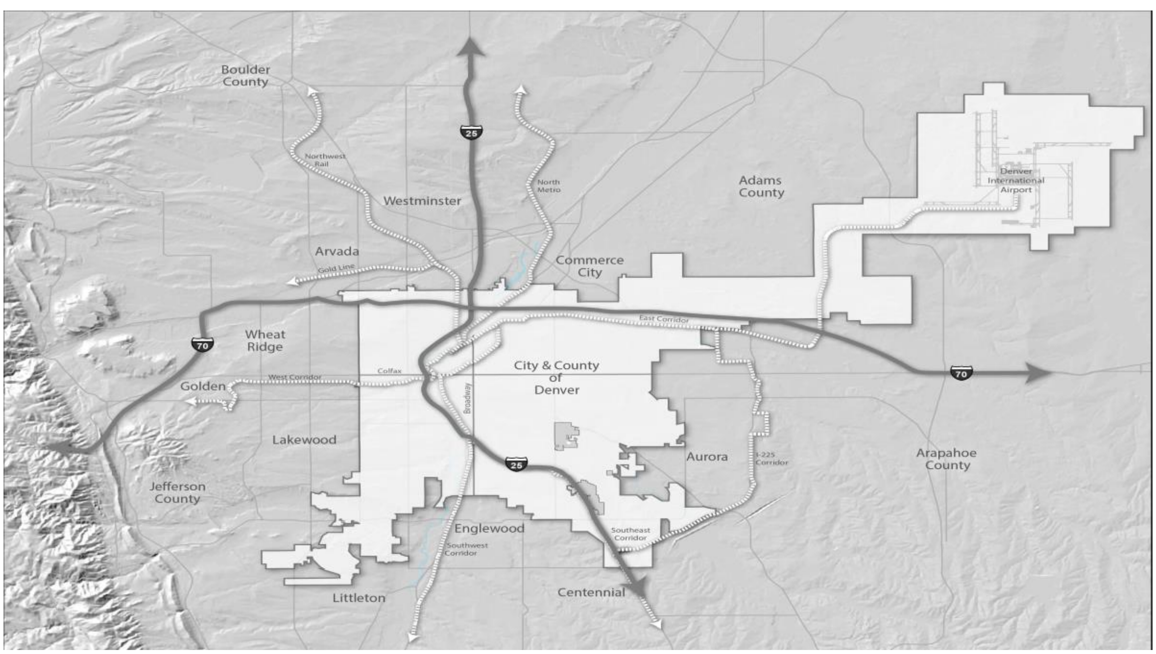

Figure 6. City of Denver county boundaries (Denver, 2017b).

Analytical datasets

These included datasets such as schools, child care centers, commercial land use districts, medical and recreational marijuana stores, where constraints are derived. These datasets also included libraries, liquor stores, recreational centers that served as factors. Straight line distances were computed from each suitability constraint and factor, using a Euclidean distance tool. Euclidean distance is an ArcGIS tool that gives the distance from each raster cell to its closest source (ESRI, 2016).

Constraints

The suitability constraints included both legislative and environmental restrictions. The legislative constraints included the following;

- Distance from schools: These were Euclidean distances from schools' parcels including elementary schools, middle schools, high schools, colleges, locations for afterschool programs, technical schools and universities located within the City of Denver.
- Distance from licenced child care centers: These were Euclidean distances from active licenced child care facilities' parcels within the City of Denver in Colorado.
- Distance from medical marijuana stores: These were Euclidean distances from buildings designated as medical marijuana stores. Even though the same marijuana products are sold in medical and retail stores, their purpose is distinct.

- Distance from recreational marijuana stores: These were Euclidean distances from the edge of commercial buildings designated as recreational or retail marijuana stores.

The environmental restrictions are as follows;

- Non-residential land use districts: These were exempted land uses classification areas stated in the Marijuana location guide as designated residential zones such as ‘Single Family Duplex', 'Single Family Residential' and 'Urban Residential'.
- Roadway areas: These were exempted land uses used for roadways, not suitable for situating store locations. The roadways were represented by the area covered by the street network which consisted of highways, major roads, and collectors. The street network contained table fields such as street type, street direction, street name, beginning address number on the left and right side of a street segment, ending address number on the left and right side of a street segment.
- Hydrology: These were prohibited areas occupied by hydrological features such as rivers, lakes, creeks, streams and waterways, not suitable for situating store locations.

Factors

These were liquor stores, recreational centers and libraries.

- Distance from liquor stores: These were Euclidean distances from active liquor stores in Denver.

- Distance from recreational centers: These were Euclidean distances from recreational centers including playgrounds, parks and public parks where children gather to play, interact and have a leisure time.
- Distance from public library: These were Euclidean distances from public libraries locations within the City.

Evidence Generated for the Administrative Study

Procedures

The topology toolset served as a toolset to investigate the compliance rate within the same layer (recreational marijuana stores) while the 'select by location' tool evaluated the compliance rate with other suitability constraints. The topology toolset was executed based on topology rules within a feature class to determine the permissible spatial relationship between features (ESRI, 2019b).

First, the distance separations between features within the same feature class was determined using a buffer tool. Second, the topological rule (must not overlap) was used to test and validate distance separations based on a set of integrity checks to identify area features that were in violation of the topology rules, and thereby flag them accordingly.

The 'select by location' tool made a spatial selection of features based on their location relative to other features in another feature layer (ESRI, 2019c). For instance, this tool was able to select the number of recreational marijuana stores that were 1000 feet away or within 1000 feet of other factors and constraints represented by spatial layers. A spatial selection method (are within a distance of the source layer) was applied as a spatial relationship rule to select features from the target layer (ESRI, 2019c). This selection method created a buffer distance around the property and returned all the properties intersecting the buffer zones and a switch selection toggled the previous selection to identify the property that are 1000 feet away.

Ethical Concerns

Spatial data in Denver open data catalog are datasets in the public domain which is good for re-use in terms of future research by the internal and external stakeholders. There are several ethical considerations on data re-use which are centered around trust, informed content, right to privacy, confidentiality and protection from harm (Babbie, 2017). The city of Denver has demonstrated its duty to its citizen by excluding sensitive and private information such as personal name, bank details, email address and telephone number of marijuana store owners. It is Denver's moral responsibility and obligation to protect the privacy rights and dignity of its citizens, uphold its reputation before customers and avoid legal implications at all cost. The ethical responsibility on data re-use demonstrates that the city of Denver cares about the values of transparency and openness to business owners and other social groups related to the marijuana policy.

I reduced any form of bias during the geocoding process to create spatial locations out of the spreadsheet list of recreational marijuana store locations provided to me by a Denver administrative staff. Since the research was focused about location such as addresses, I also concealed the attributional identity of business owners during spatial data analysis, information extraction and result presentation. The "do not harm" principle was my central focus of caution during the research even though I did not engage directly with the stakeholders. Since my research was re-using open government data, I had to obtain the Institutional Review Board (IRB)'s approval and the committee's consent to proceed with the initiation phase of the research process, thereby eliminating any negative risk that could compromise the PAS study.

Analysis and Synthesis

The analytical procedure required 3 major methodological steps:

(1) Proximity analysis to check for compliance

(2) Suitability analysis based on set distance to increase compliance

(3) A second proximity analysis to check on increased compliance based on new distance

Proximity Analysis

The proximity analysis was performed between recreational marijuana stores to measure the separation distances. A straight distance, also known as 'crow flies' distance was used for proximity analysis, to examine store locations within equal distances (ESRI, 2016b). The buffer and select by location tools are common proximity tools that were employed to evaluate the compliance rate for the legislative requirement of recreational marijuana store locations. As mentioned in the legislative requirement, all restrictive distances are measured from the property line and building edge (Denver, 2018b).

The store locations are polygon shapes from which protected zones are delineated around the property line as a critical distance of compliance. According to the recreational marijuana legislation, distance restrictions are set to 1000 feet (Denver, 2018b), but a subsequent test of compliance at distance separations of 950, 850, 750, 650 feet were initiated if buffer-distance overlaps were detected. This distance separation ensured that the violation of legislative requirements is at its minimum, thereby offering an improvement to the Denver's Code of Ordinance.

Suitability Analysis

The application of suitability analysis qualifies, compares and ranks candidates' sites based on multiple weighted criteria (ESRI, 2018). In order to attain compliance, these criteria were first defined by the separation distances in the Denver's legislative requirement and additional distance separations were recommended to situate recreational marijuana stores. The suitability analysis process comprised of both factor and constraints evaluation to obtain the final suitability map that improves compliance to the Denver's legislative requirement (see Figure 7).

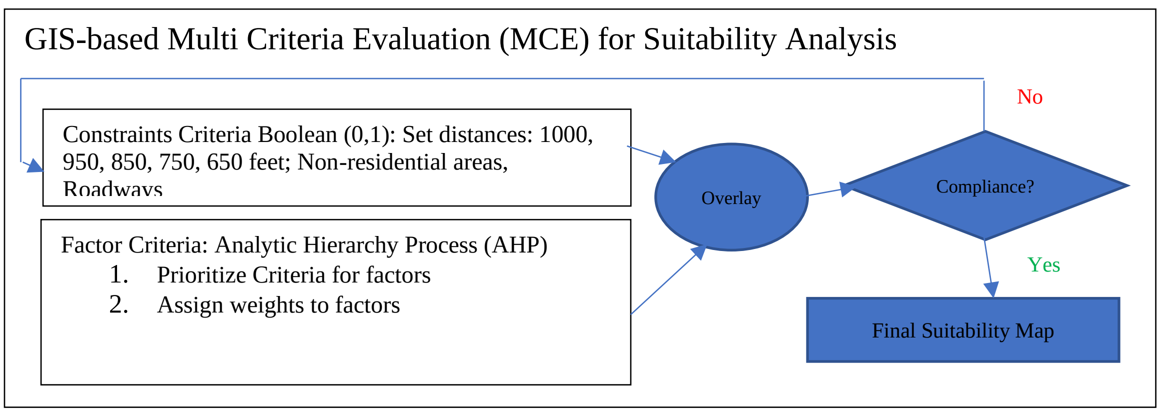

Figure 7. MCE process for suitability analysis.

The following steps were employed in the MCE:

Step 1 - determine the criteria

Under MCE, factors and constraints are defined as the set of criteria or requirements that were employed for the decision-making process to select suitable sites

(Muhsin et. al, 2017). Muhsin et. al (2017) describes a factor as a criterion that enhances or detracts from a suitability of a location under consideration. Suitability factors were generated from spatial layers such as recreational facilities, libraries, liquor stores whereas constraints were fixed distances within a cycle of suitability analysis. The factors in the Table 3 below were shown as a selection criterion with their level of suitability grouping. Table 4 illustrates constraints based on the Denver legislative requirements.

Table 3

Suitability Factors

Selection Criteria	Suitability Grouping			
	Unsuitable	Less Suitable	Suitable	Most Suitable
Distance to libraries	< 1000 feet or 304.8 metres	1000 – 1100 feet	1100 – 1200 feet	>1200 feet
Distance to liquor stores	< 1000 feet or 304.8 metres	1000 – 1100 feet	1100 – 1200 feet	>1200 feet
Distance to recreational facilities, playgrounds, parks, and golf courses	< 1000 feet or 304.8 metres	1000 – 1100 feet	1100 – 1200 feet	>1200 feet

Table 4

Suitability Constraints

Constraint Criteria	Buffer (Feet/Metres)/Area
Schools	1000 feet or 304.8 metres; (950, 850, 750, 650 feet)
Licensed Child care centers	1000 feet or 304.8 metres; 950, 850, 750, 650 feet
Retail/Recreational Marijuana centers	1000 feet or 304.8 metres; 950, 850, 750, 650 feet
Medical Marijuana centers	1000 feet or 304.8 metres; 950, 850, 750, 650 feet
Road Areas	Away from
Commercial Land Use (Non-residential)	Completely within

These criteria (factors and constraints) were set at 1000 feet or 304.8 metres at the first cycle of suitability analysis but decreased to distance separations of 950, 850, 750, 650 feet in order to meet compliance. Muhsin et. al (2017) also described constraints as a criterion to limit or restrict the alternative under consideration, thereby making them unsuitable. Other constraints in this research were unsuitable and restrictive areas such as roads, residential land use, water body which were set as environmental constraints. These unsuitable areas are usually represented by a Boolean mask in the process model. ESRI (2018a) describes a process model as a geoprocessing model that describes the interaction of spatial objects with a large suite of geospatial tools to predict or generate an analytical result. The distance restrictions are determined using the 'Euclidean distance tool', a distance tool from the ArcGIS toolset as shown in Figure 8 below (ESRI, 2016a). ESRI (2016a) defines the Euclidean distance tool as a geoprocessing tool that gives a straight-line distance from each cell to the closest source, thereby offering distance relationship to the location of interest.

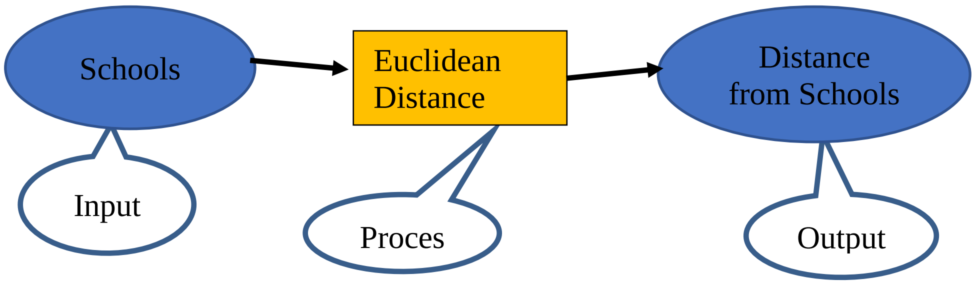

Figure 8. Euclidean tool.

The location of interest (constraints or factors) represented the source cells from which the Euclidean distance is calculated to the surrounding cells. The Euclidean algorithm calculates the Euclidean distance as floating-point distance from the center of a source cell by calculating the hypotenuse of the right-angle triangle (ESRI, 2016a) as shown in Figure 1. ESRI (2016a) describes the Euclidean distance raster as a 'crow flies' distance output calculated from cell center to cell center.

Step 2 - standardize the factors scores

This requires the transformation of cell values to a common scale, say 1 (less suitable) to 10 (more suitable). ESRI (2018a) emphasize that transformation of cell values requires a change of cell values to alternative values. The transformation of cell values by reclassification assigned values of preference with distant cells been more suitable than closer cells to the source cell. The reclassify tool is shown in Figure 9 below. In this analytical step, restriction and constraints were defined by simply setting them to a 'NoData' to exempt and remove its values from further analysis. In the process of transformation of cell values, there must be caution in reclassifying the range of values to avoid overlaps at the boundary of two input ranges (ESRI, 2018a).

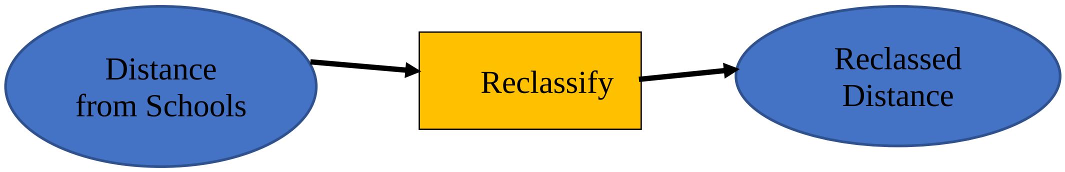

Figure 9. Reclassify tool.

However, this inclusiveness and exclusiveness is well addressed if overlapping occurs. For example, if two input ranges, 1 to 10 and 10 to 20 are reclassified as 500 and 1000 respectively as their output, then any cell input designated less or equal to 10 would be assigned the value 500 whereas cell input greater than 10, like 10.01 would be assigned the value 1000. This is imminent in classified break values used in ArcMap layer symbology.

Step 3a: weight determination of each factor using AHP (arc tool – weighted overlay)

The weighted overlay is an ArcGIS geoprocessing tool used in multiplying a percentage influence on the input raster according to their importance, as shown in figure 10 (ERSI, 2018a). Weighted Linear Combination were used to assign weights according to their importance or influence as shown in Table 8. These weights were assigned as integer values to each factor using the Weighted Overlay tool. The respective percent influence weights were represented as integer values or rounded nearest integer whose total weight must equal to 100. The weighted overlay example is presented in the example below with the first cell (Row 1, Column 1) of the first raster (InRas1) containing the value of 2 and the first cell (Row 1, Column 1) of the second raster (InRas2) containing the value of 3. The computation is as follows

$$(2 * 0.75) = 1.5 \text{ and } (3 * 0.25) = 0.75.$$

Then, the sum of the two is determined as (1.5 + 0.75) which equals 2.25. Since the result must be a rounded integer, then 2.25 is rounded to 2.

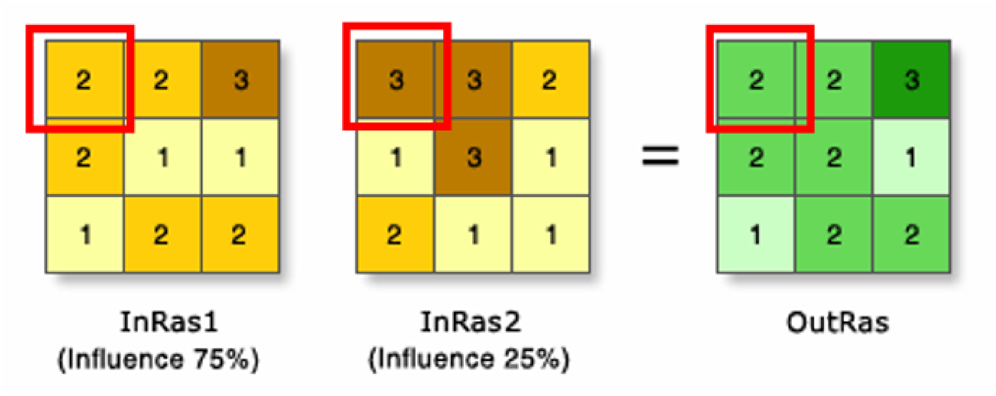

Figure 10. Overlay weighted tool (source - ERSI).

Step 3b: pairwise comparison of factors, determine constraints and aggregate the criteria

The influence was determined using the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method by Prof Thomas Saaty (Saaty, 1980), to obtain ratio scales from paired comparisons. The common measured ratio scales such as price and weights were derived from the principal Eigen vectors and the consistency index was derived from the principal Eigen value (Saaty, 1980). Out of the three factors (public library, liquor store and recreation centers etc.), the pair-wise comparison was used to know in term of distance, which factor has the most influence when in comparison with each other. Considering the 3 choice of vulnerable locations (public library, liquor store and recreation centers etc.) below, there were 3 comparisons from the method of pairwise comparison where $n = 3$

$$n = (n(n-1)) / 2 \qquad (3)\ (\text{Saaty, 1980})$$

From a subjective point of view, 3 comparisons were made resulting in a 3 by 3 matrix. The 3 comparison were as follows:

1. Liquor stores were slightly favoured when comparing it to public library. Since judgement value is on the left side, it was the reciprocal value i.e. 1/5. This is shown in Figure 12. Caulkins et. al (2016) emphasized that most marijuana consumers are also heavy alcohol drinkers, a habit which is the primary cause of most fatal accidents and loss of lives. Heavy alcohol drinkers are synonymous with most marijuana consumers and they are both likely to progress to harder drugs, thereby increasing social vulnerability.
2. Public libraries were strongly favoured when comparing it to recreational centers etc. This is shown in Figure 11. Since judgement value is on the right side, it was an actual judgement value i.e. 3
3. Liquor stores were slightly favoured when comparing it to recreational centers etc. This is shown in Figure 13. Since judgement value is on the right side, it was an actual judgement value i.e. 7

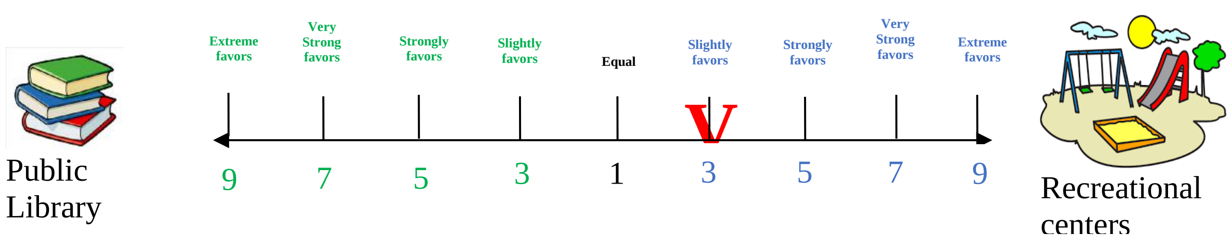

Figure 11. Comparison between public library and liquor stores.

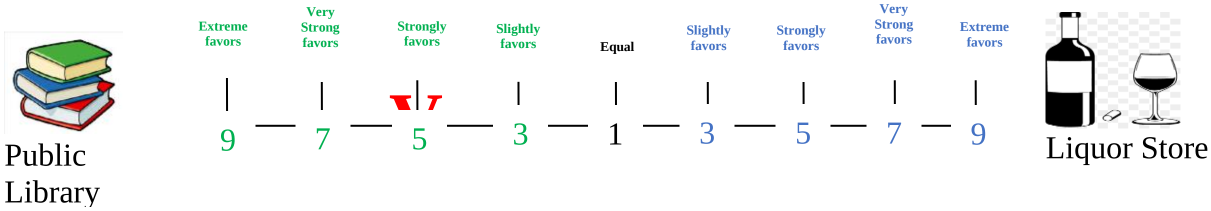

Figure 12. Comparison between public library and recreational centers etc.

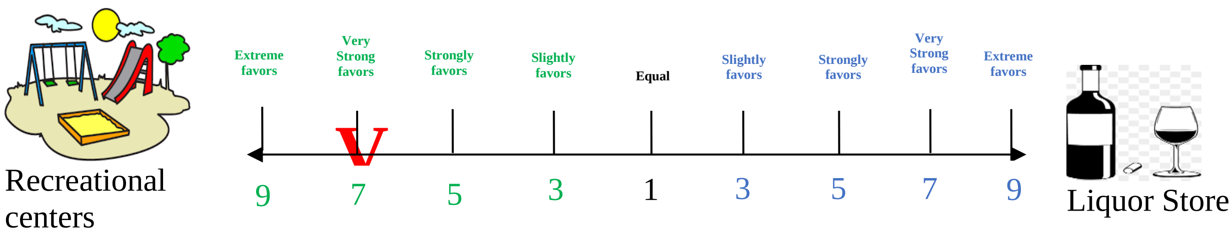

Figure 13. Comparison between liquor stores and recreational centers etc.

Filling the lower diagonal matrix with the reciprocal form of the upper diagonal matrix, I had the following matrix. This step is illustrated in Table 5. Summing each column of the reciprocal matrix, the following matrix was obtained. This step is illustrated in Table 6.

Table 5

Matrix 1

A =

	Distance to public libraries (Factor1)	Distance to recreational centers (Factor2)	Distance to liquor stores (Factor3)
Distance to public libraries (Factor1)	1	1/3	5
Distance to recreational centers (Factor2)	3	1	7
Distance to liquor stores (Factor3)	1/5	1/7	1

Table 6

Matrix 2

A =

	Distance to public libraries (Factor1)	Distance to recreational centers (Factor2)	Distance to liquor stores (Factor3)
Distance to public libraries (Factor1)	1	1/3	5
Distance to recreational centers (Factor2)	3	1	7
Distance to liquor stores (Factor3)	1/5	1/7	1
∑ Sum	21/5	31/21	13

A normalized relative weight was obtained when each element within the matrix was divided by the sum of its column. The sum of each column equals to 1. This step is illustrated in Table 7.

Table 7

Matrix 3

A =

	Distance to public libraries (Factor1)	Distance to recreational centers (Factor2)	Distance to liquor stores (Factor3)
Distance to public libraries (Factor1)	5/21	7/31	5/13
Distance to recreational centers (Factor2)	15/21	21/31	7/13
Distance to liquor stores (Factor3)	1/21	3/31	1/13
∑ Sum	1	1	1

The normalized principal Eigen vector for matrix was achieved by averaging across the 3 rows, thereby determining the weight of each factor.

$$A = 1/3 \begin{bmatrix} 5/21 & + & 7/31 & + & 5/13 \\ 15/21 & + & 21/31 & + & 7/13 \\ 1/21 & + & 3/31 & + & 1/13 \end{bmatrix} = \begin{bmatrix} 0.2828 \\ 0.6463 \\ 0.0738 \end{bmatrix}$$

Examining the relative weights shown in Table 8 below, it shows that the recreational marijuana stores was placed 2.3(=65/28) times further beyond public libraries than recreational centers and 9.23 (=65/7) times further beyond liquor stores than recreational centers in the city of Denver.

Table 8

Weight of Each Selection Criteria

Selection Criteria	AHP	Weight Influence
Distance to public libraries	0.2828	28%
Distance to recreational centers	0.6463	65%
Distance to liquor stores	0.0738	7%
∑ Sum	1	100%

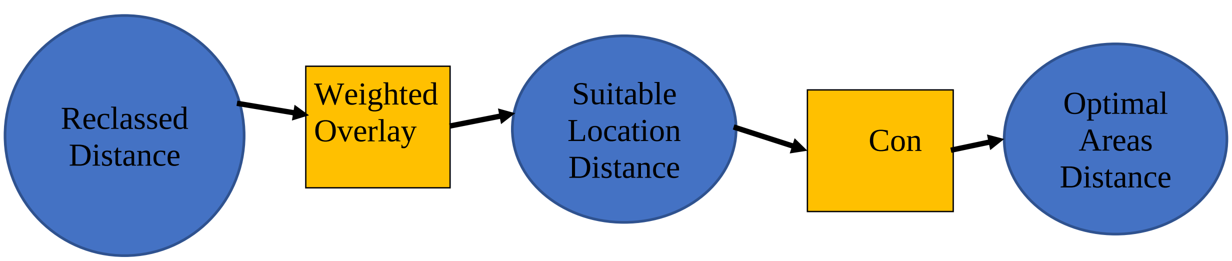

Figure 14. Weighted overlay and con tools.

The use of AHP with the GIS-based MCE approach offered an excellent decision procedure to determine weights for the factor criteria. The AHP, a structure technique for decision making was used as a framework to make mathematical pairwise comparison of relative importance between two criteria (Saaty, 1980). These weights were assigned to these factors using the weighted overlay tool as shown in Figure 14 to determine the relative importance using Saaty's nine-point weighting scale shown in Table 9:

Table 9

Scale of Pairwise Comparisons

Scale (Intensity of Importance)	Description of preference
1	Equally (Equal importance)
2	Equally to Moderately important (Intermediate value)
3	Slightly favors (Moderate importance)
4	Moderate to Strongly important (Intermediate value)
5	Strongly favors (Strong importance)
6	Strong to very strong importance (Intermediate value)
7	Very Strongly favors (Very strong importance)
8	Very strong to extreme important (Intermediate value)
9	Extreme favors (Extremely importance)

The GIS-based MCE incorporated both factors and constraint criteria which were represented as spatial distribution in map layers. Factor maps presented opportunity criteria through weighted linear combination of factor criteria whereas constraint maps contained distance restrictions that limits and prohibits the location of recreational marijuana stores to improve compliance. Within the GIS-based MCE, two important methods namely, weighted summation procedures and the Boolean overlay operation were integrated together in the formula below to achieve the final suitability.

Formula: $S = \Sigma WiFi \times \Pi Ci$ (4) (Malczewski, 1999)

Where:

S – is the composite suitability score

Wi – weights assigned to each factor

Fi – factor scores (cells)

Ci – constraints (or Boolean factors)

Σ -- sum of weighted factors

Π -- product of constraints (1-suitable, 0-unsuitable)

The composite suitability score applied in a GIS raster calculator can be illustrated in the expression below;

S = ((Factor1 * 0.2828) + (Factor2 * 0.6445) + (Factor3 *0.0738)) * cons_boolean

Step 4: validation and verification

This phase required the use of con and the majority filter tools to choose the optimal sites. The Con tool offered a conditional expression where the suitability areas were grouped into less suitable, suitable and most suitable areas. The Majority filter tool offered to clean the optimal sites by excluding 30-meters cells that were too small for siting marijuana stores. The final raster was converted to a feature class designated as an optimal site with calculated areas suitable to site a marijuana store for recreational purposes.

Summary and Conclusion

The methodology section presented a framework where analytical structure can be modified and repeated to achieve the most desirable level of compliance and recommending a feasible separation distance that reduced the number of non-compliant stores. With the GIS assisted MCE framework, current marijuana laws and regulations can be revised with the help of AHP that determines the factor weights and the legislative requirements that restricts situating of retail stores with constraint distances. The factors determined the level of suitability while constraints limit suitability based on recommended legislative requirement. This analysis within the study contributed to useful legislative knowledge and recommended to policy makers to validate their decision-making processes.

Section 4: Evaluation and Recommendations

Introduction

The section presents GIS solutions to the research problem involving compliance rates and suitability of distance separations between marijuana retailers and vulnerable locations. The PAS solutions are presented in the form of geoprocessing models, tables, maps, and statistical tests. Data collected for analysis were secondary and valid to provide credence and quality to research findings. The research purpose involves evaluating legislative distance separations and predicting new store location, thereby improving marijuana licensing requirements in Denver.

Upon request, the city of Denver provided permissions (see Appendix A) to download secondary spatial datasets. These datasets were downloaded in various data formats such as points, lines, polygons, and tables to provide credence and quality to the archival dataset suitable as evidence for the PAS. Geocoding, proximity, statistical, and suitability analysis served as core analytical strategies to answer the research question.

Evidence Generated for the Administrative Study

The topology toolset served as a proximity toolset to investigate compliance rates for recreational marijuana stores. While the select by location tool was used to evaluate compliance rates with other suitability constraints (see Table 10). Topology functionality in a geodatabase was used to flag evidence of violation within the same feature class through the must not overlay option, separating the dirty buffer areas from the compliant buffer areas (ESRI, 2016b). The selection by location tool with the intersect the source layer feature selection method was used to flag dirty areas across other spatial layers

(ESRI, 2016b). Figures 19, 21, 23, 25 show maps describing the compliance rate of retail marijuana stores with other suitability constraints at a separation distance of 650 feet. Figures 20, 22, 24, 26 show graphs describing the compliance rate of retail marijuana stores with other constraints at all separation distances (1000, 950, 850, 750 and 650 feet).

Table 10

Evidence for Administrative Study (at 1000 Feet)

No.	**Constraint**	**Compliant/Total number of locations**	**Compliance rate (%)**	**Non-compliance rate (100% – Compliance rate)**
1	Retail marijuana stores	49/167 = 0.293	29%	71%
2	Medical marijuana stores	3/167 = 0.017	2%	98%
3	Child Care centers	65/167= 0.389	39%	61%
4	Schools	68/167 = 0.407	41%	59%

Findings and Implications

Geographical Maps and Charts

The collected datasets were subject to data preparation to extract suitability constraints and factors which are represented in maps as shown in Figures 15, 16 and 17 below. Figure 15 shows a map representing legislative constraints such as retail marijuana stores, medical marijuana stores, schools, and licensed childcare centers. Figure 16 shows a map representing environmental constraints such as roads, streams, lakes, and nonresidential areas. Figure 17 shows a map representing factors such as liquor stores, libraries, and recreational centers

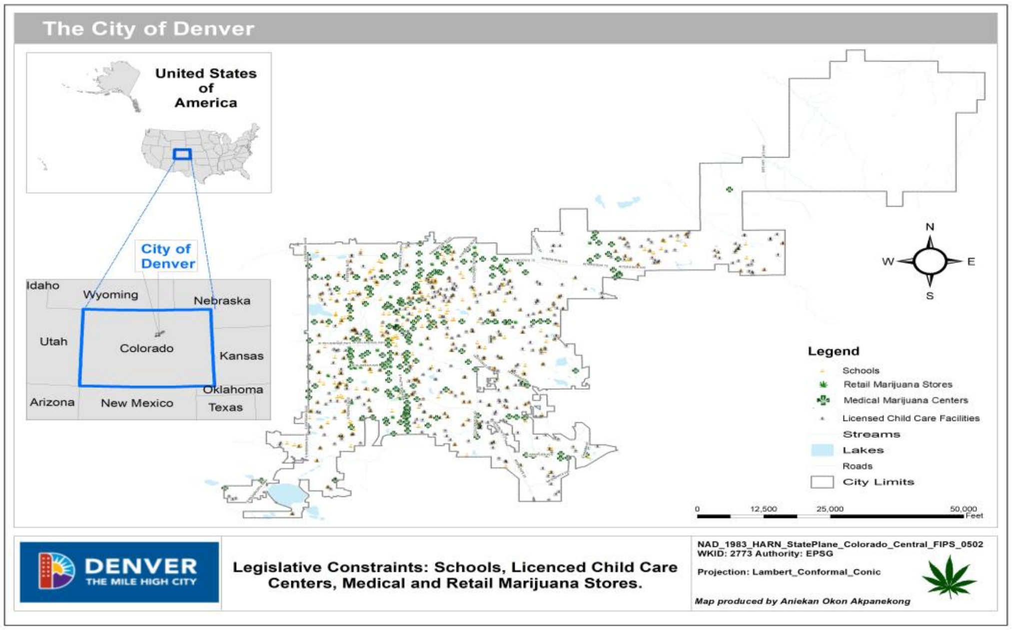

Figure 15. Legislative constraints map.

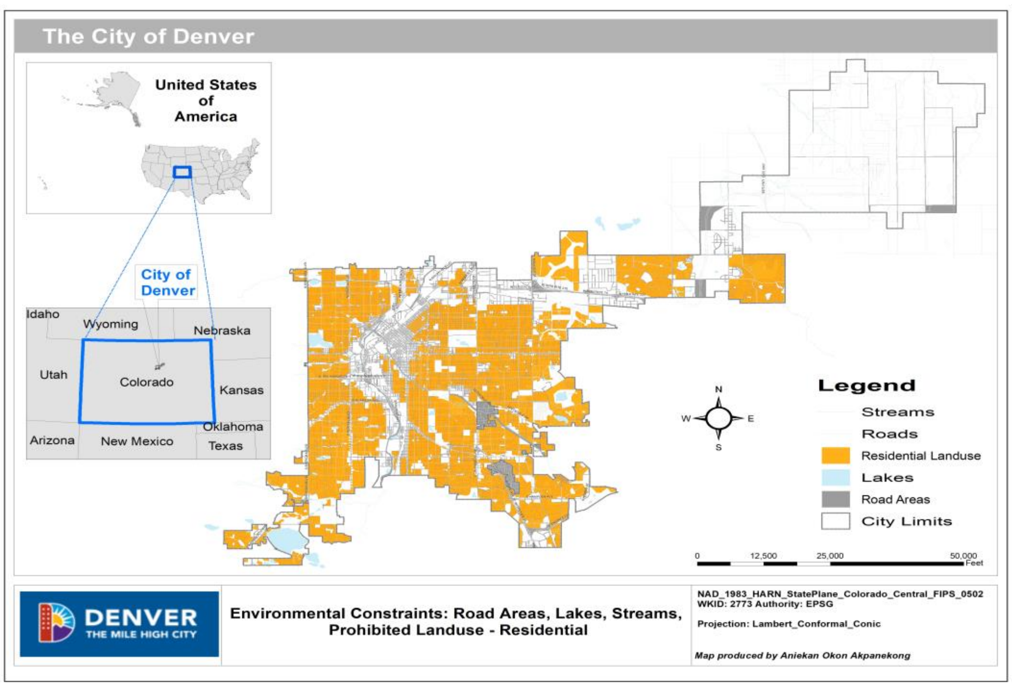

Figure 16. Environmental constraints map.

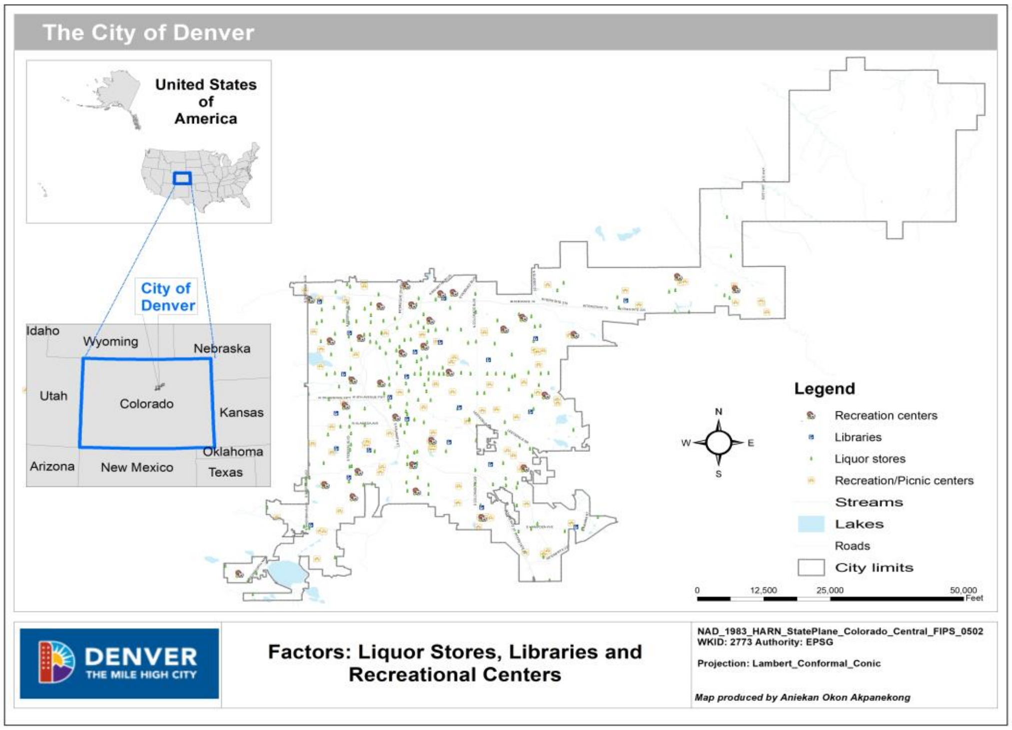

Figure 17. Suitability factor map.

Data analysis was mostly conducted using a GIS geoprocessing model to derive separation distances using Euclidean distance and buffer tools. Environmental constraints were set as a restriction, forbidding any compliance of legislative constraint or suitability factors. Legislative constraints were derived under 1000 feet (304.8 meters) reflecting Denver’s marijuana legislative requirement of distance separation. Under 1000 feet, five classes of decreasing distance separations (1000, 950, 850, 750, 650 feet) representing five cycles of analysis in Figure 18 were used to create rates of compliance and noncompliance as shown in Table 10.

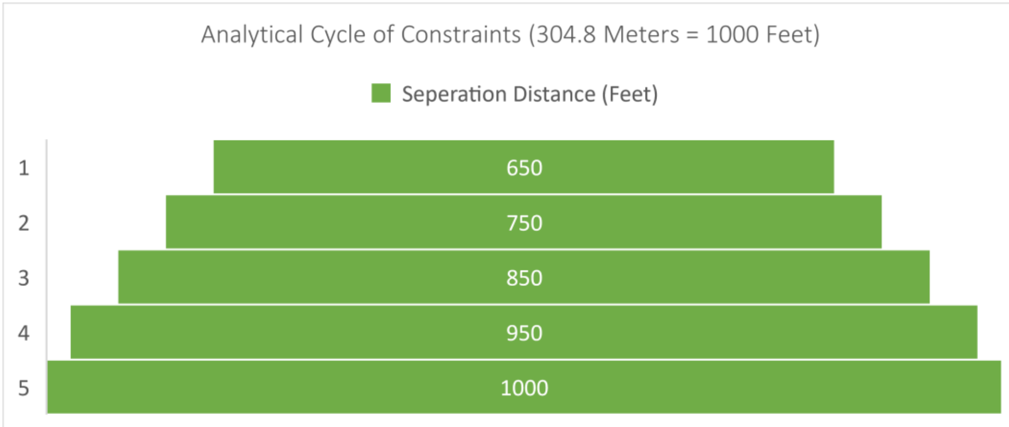

Figure 18. Five classes of constraint.

The rate of compliance and noncompliance of retail marijuana stores with other similar stores at 650 feet are represented spatially in Figure 19. The pie chart in Figure 19 represents the percentage of compliance (56%) and non-compliance (44%) at 650 feet. The subsequent rate of compliance and non-compliance at 750, 850, 950, 1000 feet are represented in Figure 20.

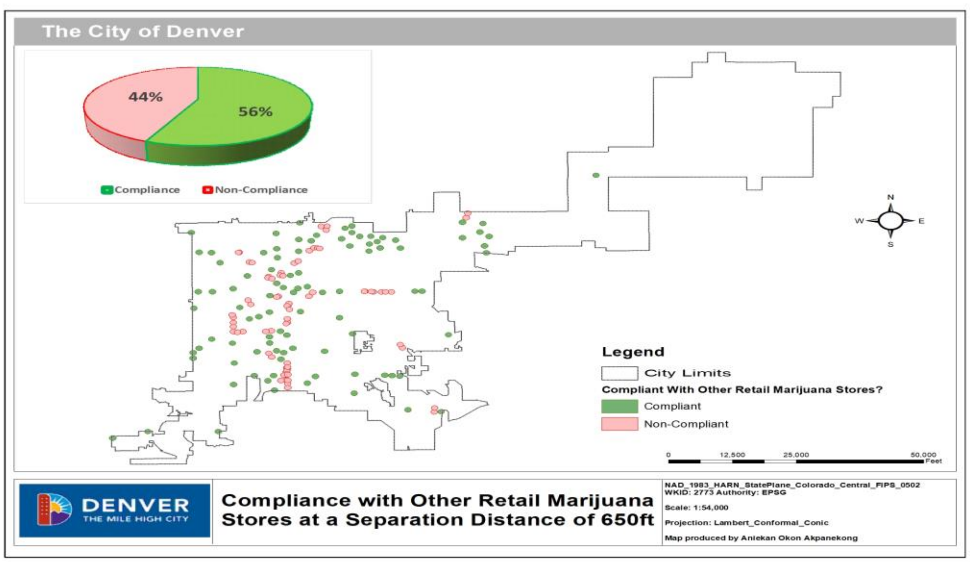

Figure 19. Compliance with other retail marijuana stores at 650 feet.

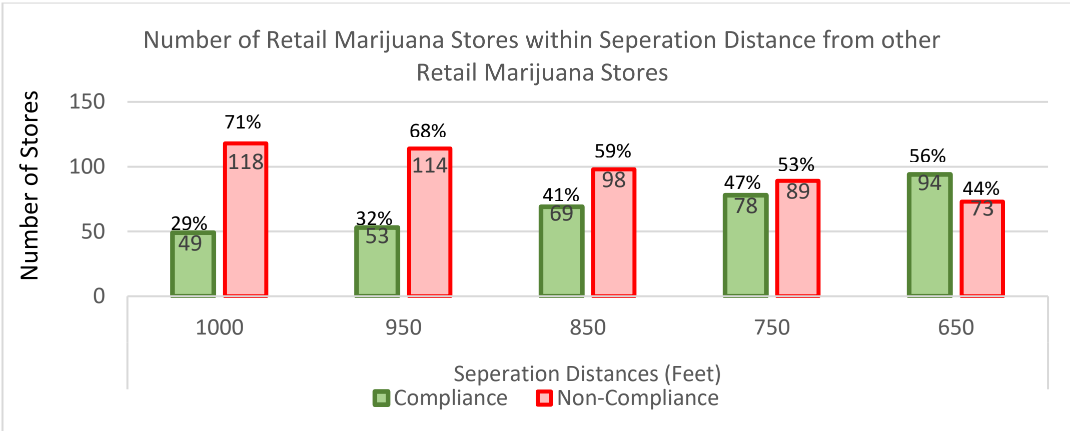

Figure 20. Graph of the decreased distance between retail marijuana stores.

The rate of compliance and non-compliance of retail marijuana stores with medical marijuana stores at 650 feet separation distance are represented spatially on the maps shown in Figure 21. The pie chart in Figure 21 represents the percentage of compliance (7%) and non-compliance (93%) at 650 feet. The subsequent rate of compliance and non-compliance at 750, 850, 950, 1000 feet are represented graphically on the chart in Figure 22.

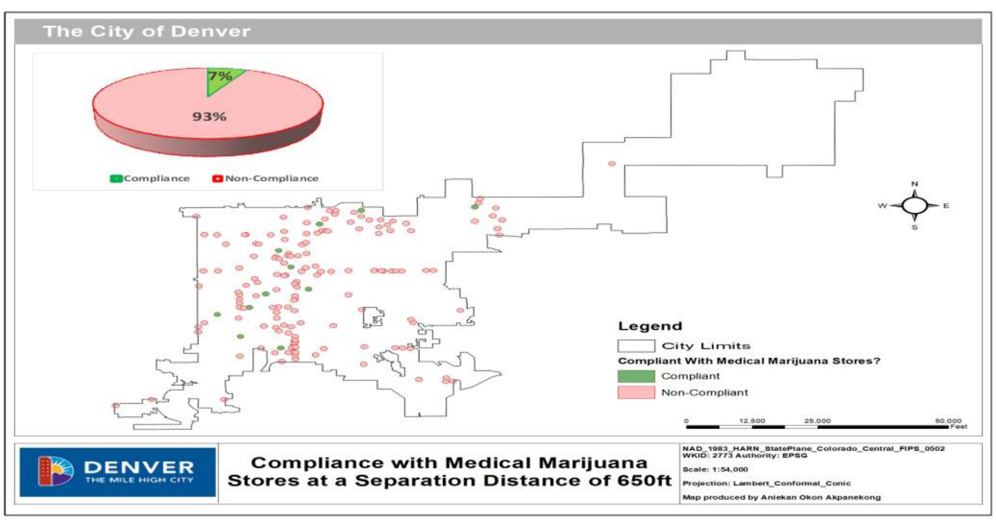

Figure 21. Compliance with other medical marijuana stores at 650 feet.

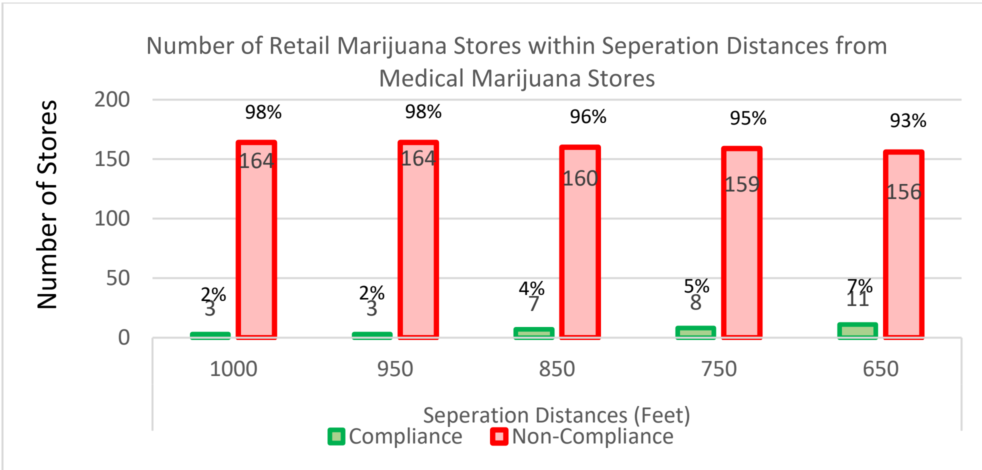

Figure 22. Graph of decreased distance from retail marijuana stores to medical marijuana stores.

The rate of compliance and non-compliance of retail marijuana stores with licensed childcare centers at 650 feet separation distance are spatially represented on the maps as shown in Figure 23. The pie chart in Figure 23 represents the percentage of compliance (68%) and non-compliance (32%) at 650 feet. The subsequent rate of compliance and non-compliance at 750, 850, 950, 1000 feet are represented graphically on the chart in Figure 24.

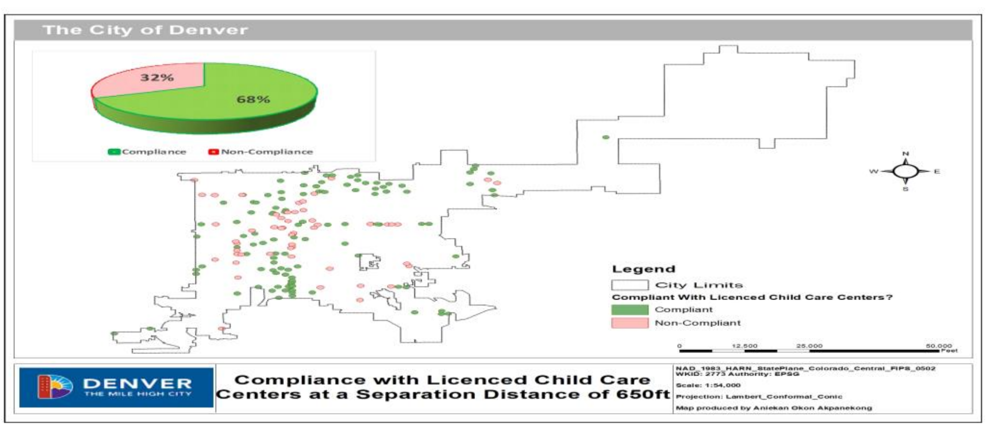

Figure 23. Compliance with licensed childcare centers at 650 feet.

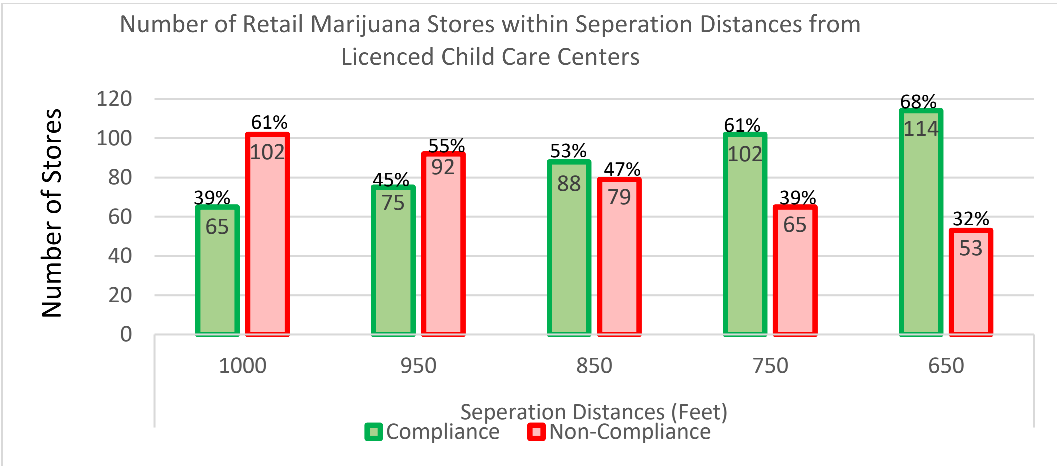

Figure 24. Graph of decreased distance from retail marijuana stores to licensed childcare centers.

The rate of compliance and non-compliance of retail marijuana stores with school locations at 650 feet separation distance are spatially represented on the maps as shown in Figures 25. The pie chart in Figure 25 represents the percentage of compliance (70%) and non-compliance (30%) at 650 feet. The subsequent rate of compliance and non-compliance at 750, 850, 950, 1000 feet are represented graphically on the chart in Figure 26.

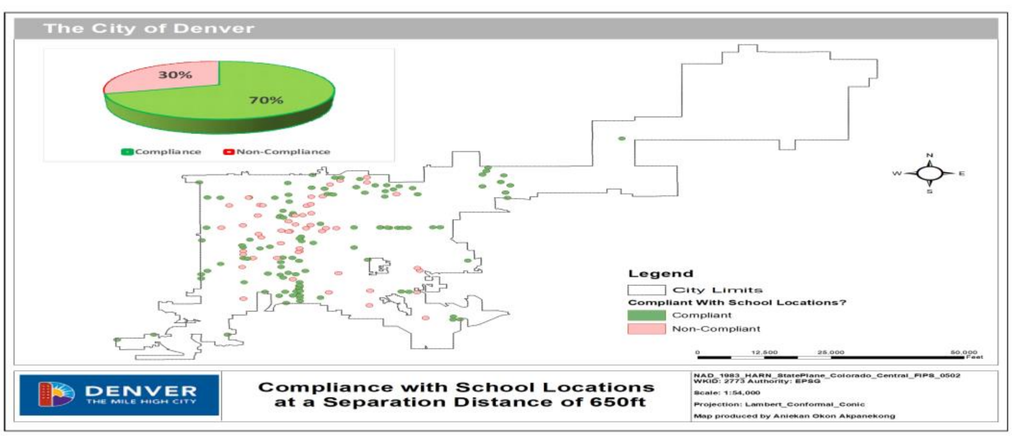

Figure 25. Compliance with school locations at 650 feet.

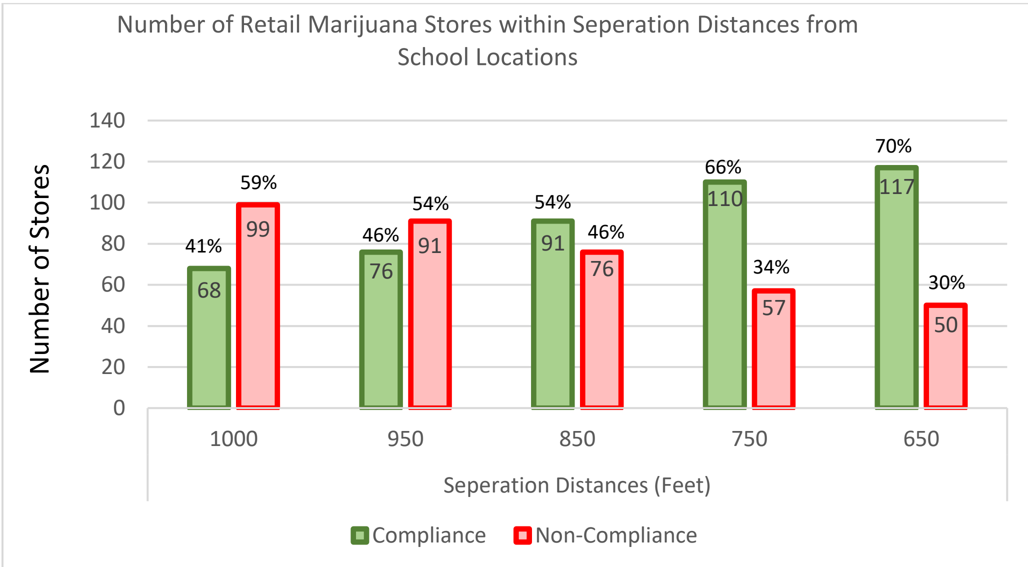

Figure 26. Graph of decreased distance from retail marijuana stores to school locations.

Compliance rate has increased from 29% at 1000 feet to 56% at 650 feet, which is about twice the initial rate. There is significant progress at this point and the rate of compliance increases with decreased distance. Table 11 below shows the respective compliant and non-complaint rate for each legislative constraint at 650 feet.

Table 11

Evidence for Administrative Study (at 650 Feet) to Reduce Social Vulnerability

No.	**Constraint**	**Compliant/Total number of locations**	**Compliance rate (%)**	**Non-compliance rate (100% – Compliance rate)**
1	Retail marijuana stores	94/167 = 0.563	56%	44%
2	Medical marijuana stores	11/167 = 0.065	7%	93%
3	Child Care centers	114/167= 0.682	68%	32%
4	Schools	117/167 = 0.700	70%	30%

Proximity Analysis Using GIS Near Tool

The separation distances from every retail marijuana store to the nearest legislative constraint was extracted using the GIS Near tool from the proximity toolset. Figure 27 is a histogram creating in ArcGIS representing the separation distances measured in meters. The graph also shows that the first separation distance class between 0 and 63.83 meters are from 143 stores out of a total of 167 retail marijuana stores. The extracted separation distances within the retail marijuana store feature class were exported into a table for a one sample *t*- test in Statistical Package for the Social Sciences (SSPS).

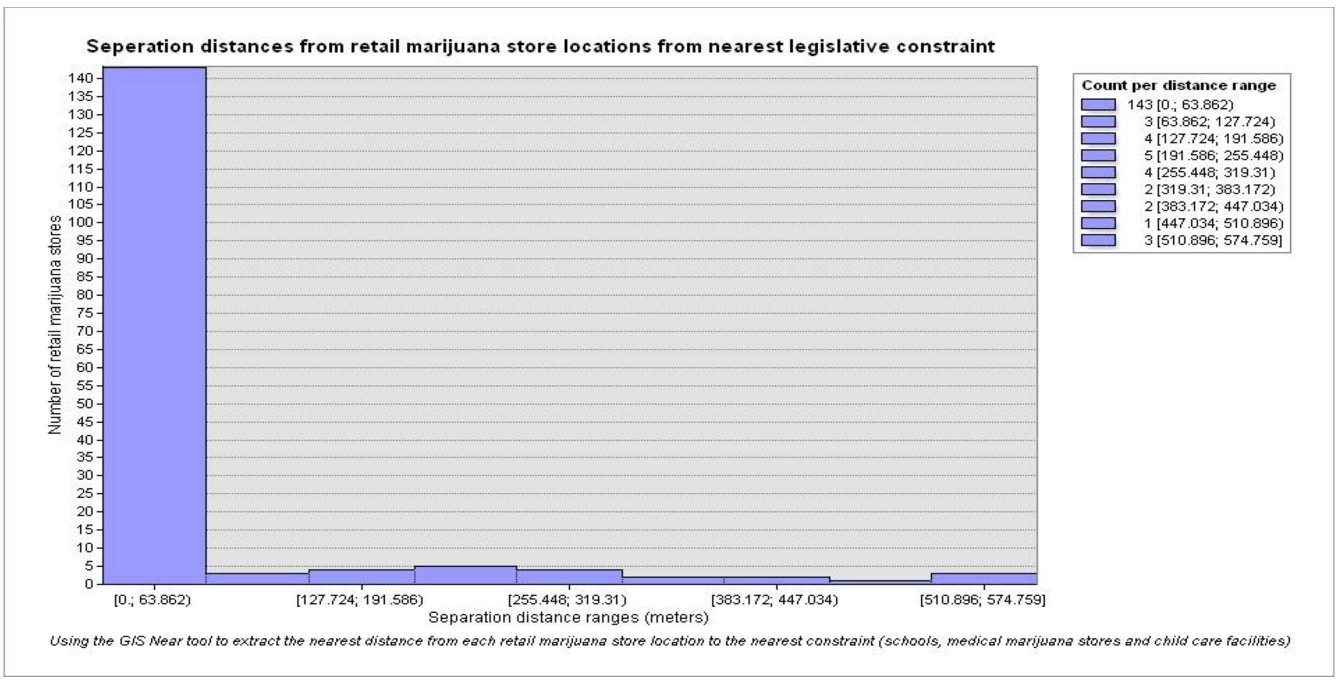

Figure 27. Separation distances using the GIS near tool from the proximity toolset.

Statistical Test Using the One Sample *t*-test

A quick data check was performed by plotting a histogram of separation distance of retail marijuana stores before running some statistical test. The histogram of separation distance created in SSPS is shown in figure 28. This provided a basic understanding of what the data looks like through its summary statistics. The histogram is based on a sample size of 56 separation distances with a mean of 59.05 and standard deviation of 143.43, with no missing values.

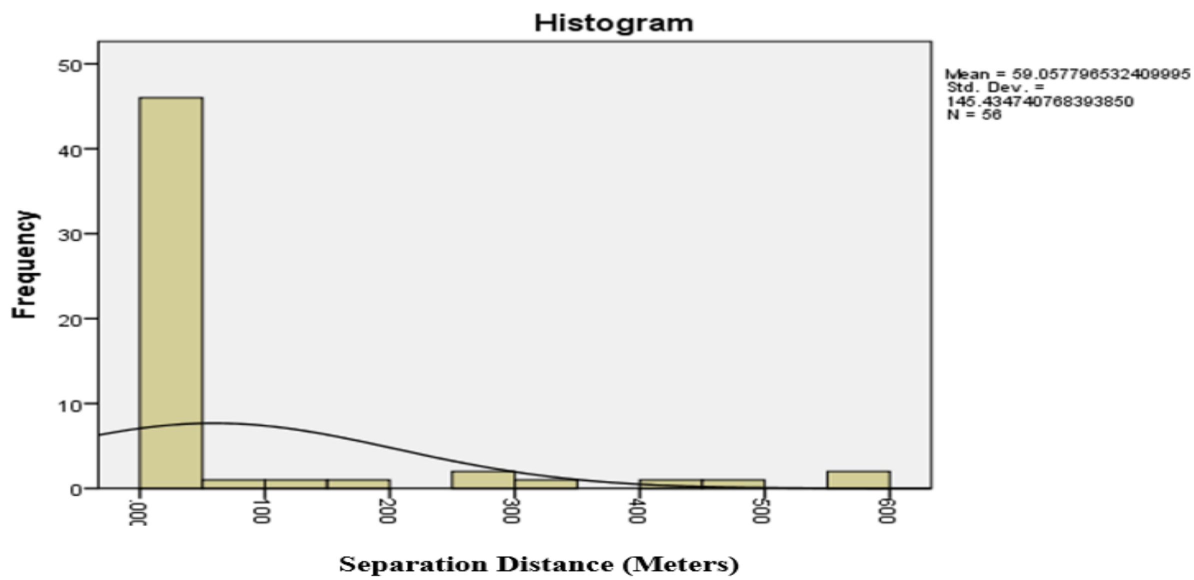

Figure 28. Histogram of separation distances for retail marijuana stores.

Table 12 is the one-sample statistics table that presents the relevant inferential statistics. The result of the one-sample *t*-test is shown in Table 13 below. From both tables, the result shows that

1. A one-sample *t*-test was run to determine whether the separation distance from recreational marijuana stores was different to normal, a separation distance of 304.8 meters

2. A mean separation distance (M = 59.05, SD = 145.43) was statistically significantly lower than the population 'normal' separation distance of 304.8 meters, a statistically mean difference of 245.74, 95% CI [206.79 to 284.68], $t(55) = -12.645$, $p = 0.000$

3. There was a statistically significant difference between means ($p < .05$) and, therefore I have rejected the null hypothesis that distance restrictions for situated recreational marijuana stores are enforced and accept the alternative hypothesis that they are not enforced.

Table 12

One-Sample t-Test Statistics

One-Sample Statistics				
	N	Mean	Std. Deviation	Std. Error Mean
Separation Distance (Meters)	56	59.05	145.43	19.43

Table 13

One-Sample t-Test

One-Sample Test						
	Test Value = 304.8					
					95% Confidence Interval of the Difference	
	t	*df*	Sig. (2-tailed)	Mean Difference	Lower	Upper
Separation Distance (Meters)	-12.645	55	.000	-245.74	-284.68	-206.79

The one-sample *t*-test indicates that the legislation for the separation distances for the current retail marijuana store locations are not completely enforced as evidenced by a lack of compliance with the required statutory distance compliance. After the above investigation, there was an indication of non-compliance from the inferential statistics in Table 13. In response, a further step of post hoc modeling using GIS suitability was applied to improve the quality of the research and offer a positive change to the retail marijuana legislation problem. To improve the situation, a GIS suitability analysis was performed to create more suitability areas to add credence to violated store locations and provide compliant areas to situate future stores.

GIS Suitability Analysis

The distance from every factor and constraints were ranked according to a measure of suitability on a common measurement scale from 1 (good) to 10 (best or most preferable) site using the reclassify tool. The legislative constraint was ranked with the first class of suitability between 0 and 304.8 meters, varying across the 5 classes of decreasing distance separations. Figures 29 to 31 below shows the ranking of distance from the 3 suitability factors.

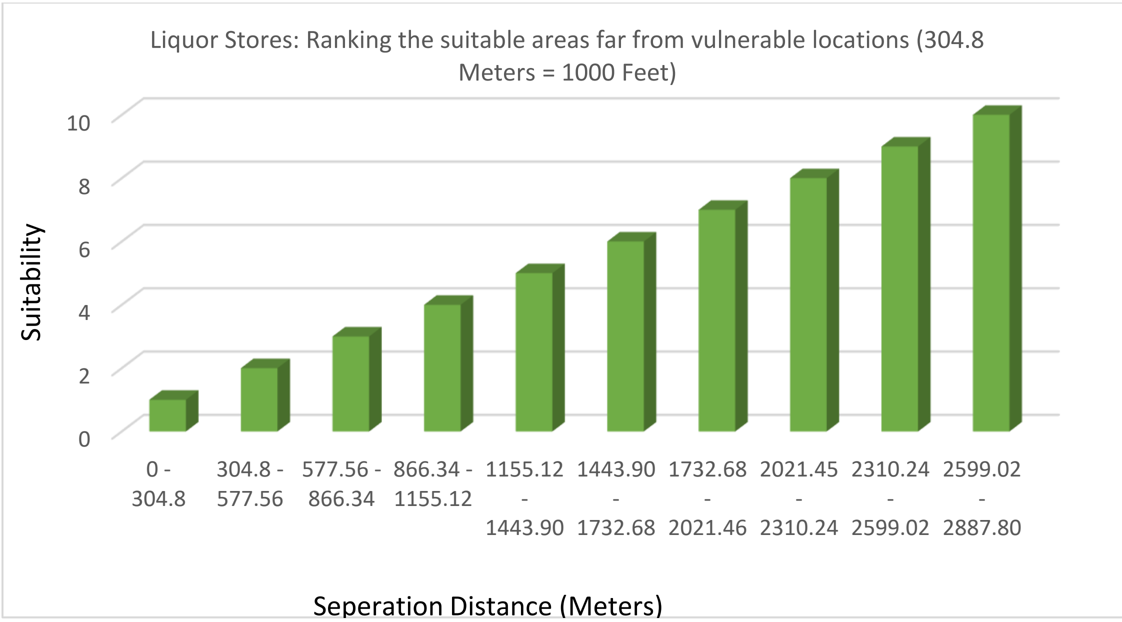

Figure 29. Ranking of areas away from liquor stores.

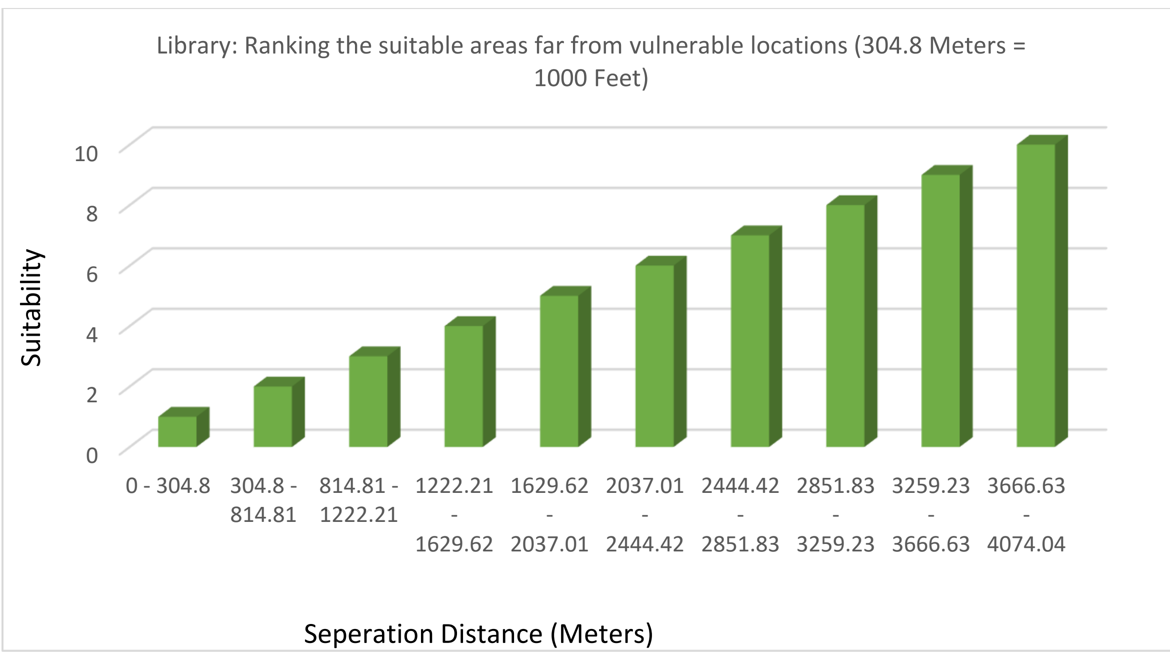

Figure 30. Ranking of areas away from public libraries.

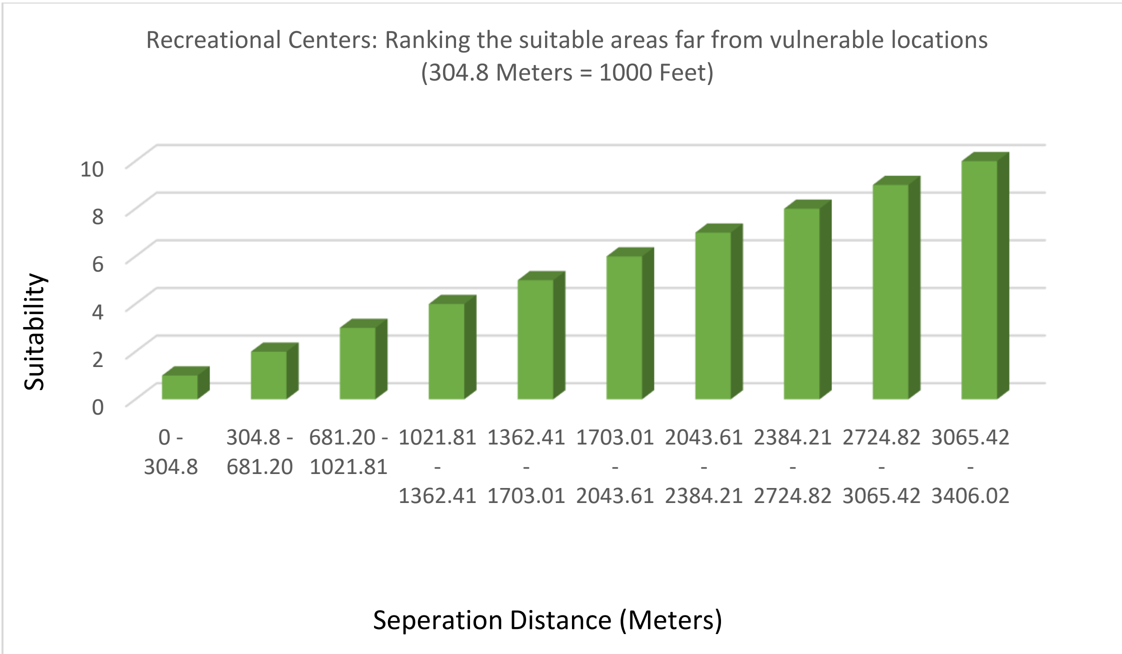

Figure 31. Ranking of areas away from recreational centers.

Geoprocessing Model

The geoprocessing model is a schematic representation of the GIS analytical process with blue oval shapes representing the input layers, the rectangle with rounded corners representing the geoprocessing tool and the green oval shape representing the result. The resulting GIS layers, represented by the green oval shape, can serve as an input to the next geoprocessing tool until the final resulting layer is obtained. The entire geoprocessing model is segmented into 4 models, with the first three models (legislative constraint, environmental constraint, suitability factor) combined with the weighted overlay to create the suitability map. Using the AHP, the suitability factors (distance to the library - 28%, distance to recreational centers - 65% and distance to liquor stores - 7%) were weighted to provide relative importance in the suitability model.

Model 1: This sub model as shown in Figure 32 created the legislative constraint with datasets such as retail marijuana store, medical marijuana stores, childcare centers and schools

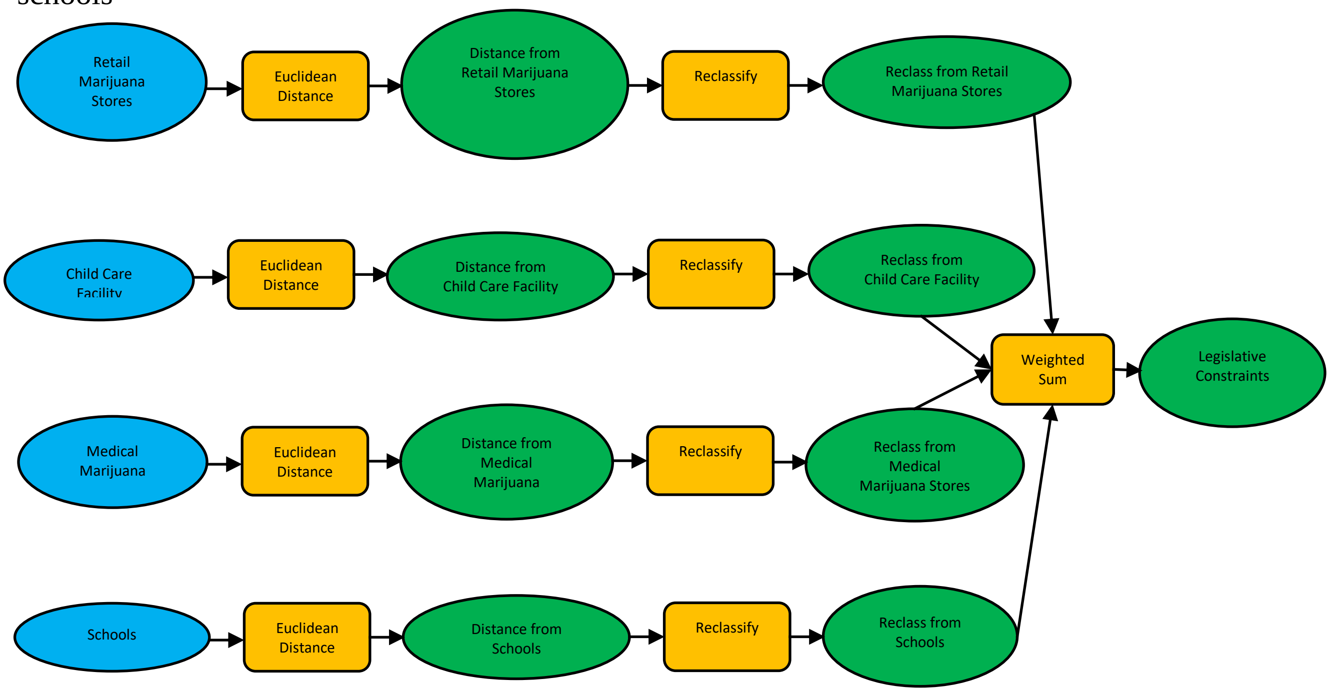

Figure 32. Legislative constraints.

Model 2: This submodel as shown in Figure 33 created the environment constraint with datasets such as the stream network, lakes, road areas, and residential land use.

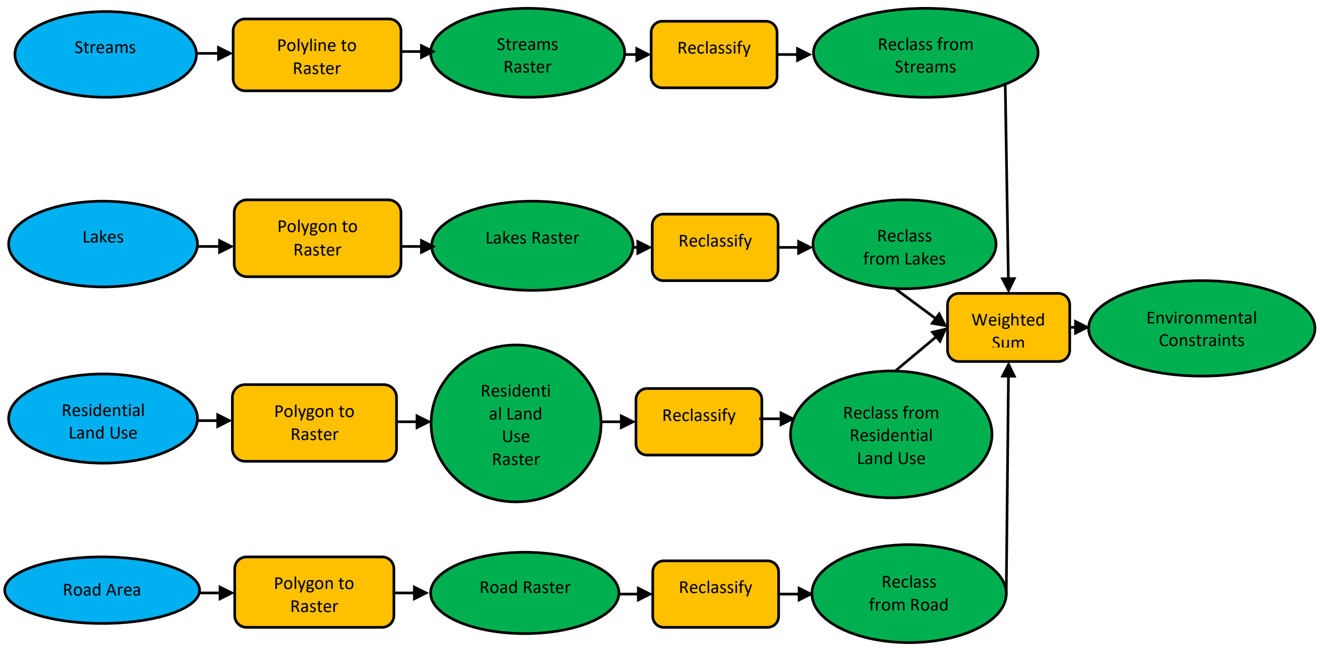

Figure 33. Environmental constraints.

Model 3: This sub model as shown in Figure 34 created the suitability factors with datasets such as the public library, liquor stores, and recreational centers.

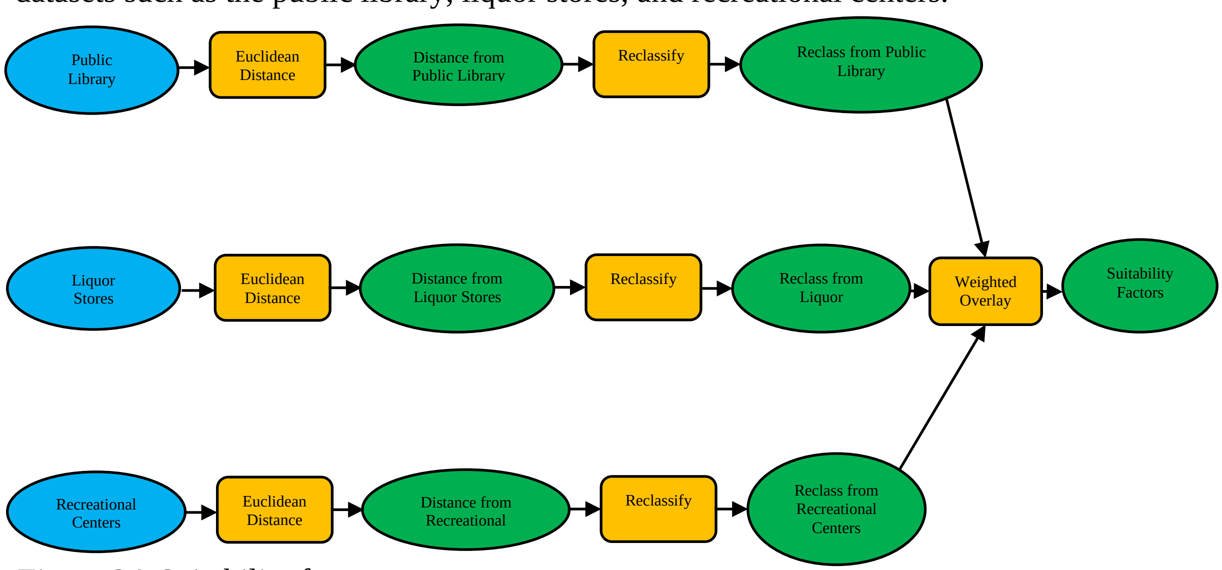

Figure 34. Suitability factors.

Model 4: This is the main model as shown in Figure 35 combining models 1, 2, 3 with the weighted overlay tool to obtain the final suitability map in Figure 36.

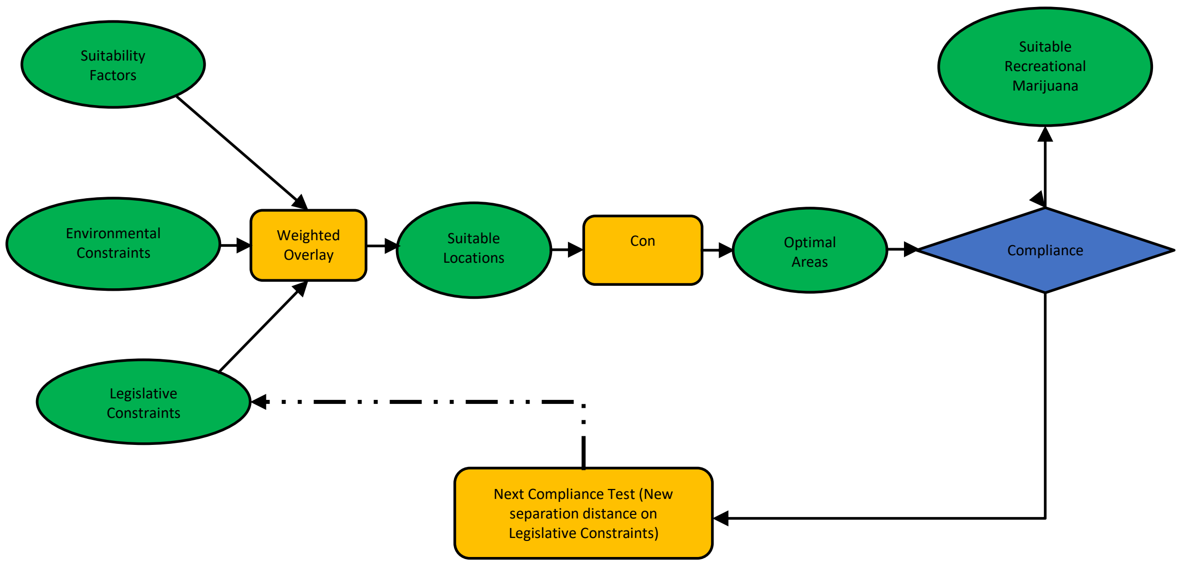

Figure 35. Combining suitability factors, legislative and environmental constraints.

Suitability Map

The suitability map shows the suitability value for every location required to situate retail marijuana store which is in conformity with the suitability factors, environmental and legislative constraints. The suitability values are designated for suitable locations, ranking them into suitable, more suitable and most suitable areas within the spatial extent of Denver. The non-designated areas are indicated as conflict areas not suitable for situating a retail marijuana store.

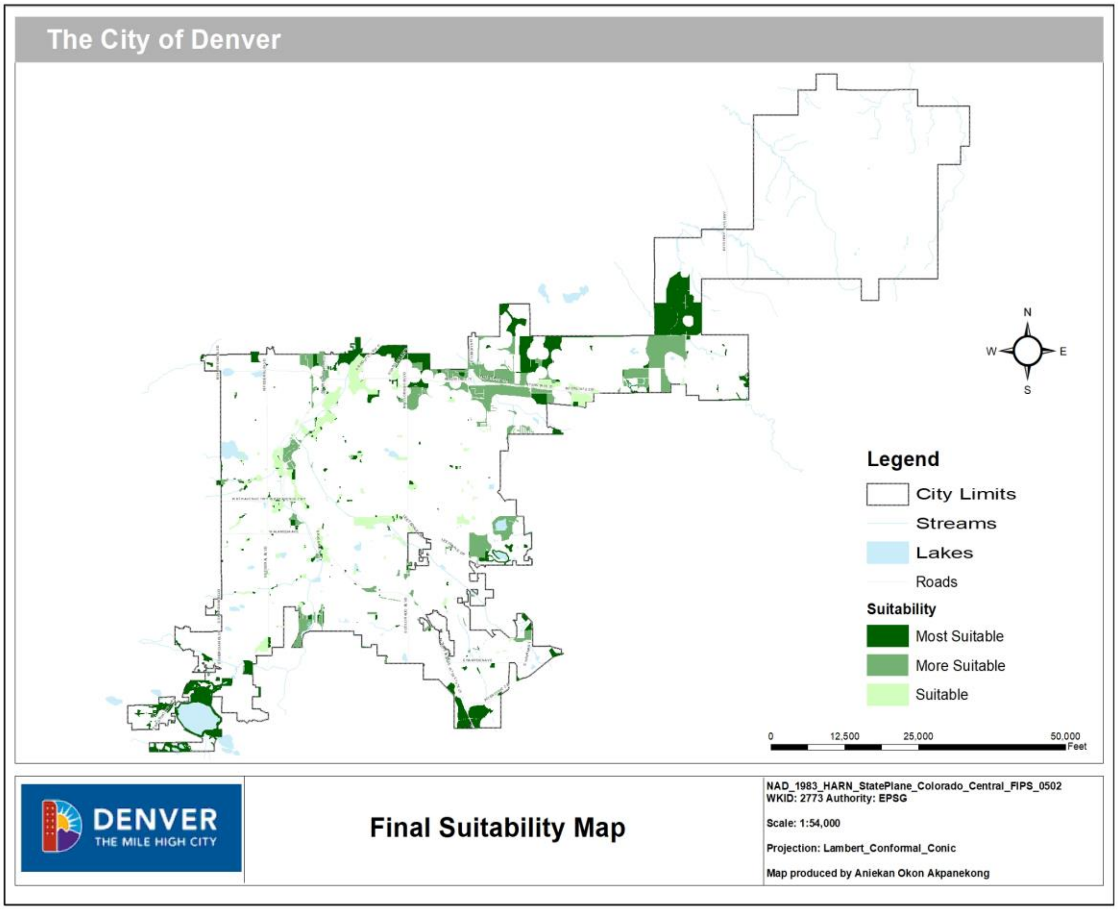

Figure 36. Final suitability map.

Implications for Social Change

The PAS evaluates the effectiveness of recreational marijuana legislation while achieving social change in Denver. This effectiveness is measured by the compliance rate and how this rate can be increased to protect social vulnerability and uphold public health and safety. The abuse of the marijuana legislative requirements by applicants indicates the violation of the law which could be intentional by the store applicants. The abuse could also be through the grandfathering situation which is a lack of administrative supervision in their investigative function to know who was there first and enforce the separation distances stated in legislative requirements.

Seperation distance stated in Denver's retail marijuana legislation are not enforced, indicating a lack of compliance by store owners and a failure on the part of the city licencing and zoning officers to enforce Denver's retail marijuana legislation. Relocation of violated retail marijuana stores with the stated legislative distance restrictions must be enforced and its implementation must be monitored by city licencing and zoning officers. To also avoid future violation of pre-existing retail marijuana stores, the same distance seperation must be enforced and applicable while situating new locations for legislative constraint and suitability factors. Since distance is related to two locations or end points, violation of the legalation from the end of new legislative constraints and suitability factors, and from the end of the retail marijuana stores must be avoided to maintain compliance.

Recommendations

The present retail marijuana legislation has not been completely implemented in Denver because of the grandfathering provision. This provision exempted pre-existing stores leading to the violation of the distance restrictions as stated in the licensing requirement. At the ushering of the first wave of retail marijuana stores, applicants had to conduct their own research and investigations without adhering completely to the licensing requirement, thereby compromising the distance restrictions between stores and vulnerable locations.

I recommend that the separation distances should be reduced from 1000 feet to 650 feet which increased compliance rate from 29% to 56%. At 29%, 49 retail marijuana stores complied at 1000 feet separation distance. At 650 feet, an additional 45 retail stores can be added to achieve a 56% compliance rate. This is almost twice the initial compliance rate, indicating increased compliance to the retail marijuana legislation.

The lack of compliance with the legislation creates a liability risk for the city of Denver. Further research is required to understand the risk this poses. If the risk is deemed to be significant then I see two possible paths forward. Denver can either change their marijuana policy so that more stores are complying. However, they will still have a 44% rate of non-compliance for retail marijuana stores. If they choose this option, further analysis needs to be done on the impact on the vulnerable sector. Second, they can enforce the law and require stores to relocate, merge or close. However, before proceeding with this alternative further research is required on the economic impact including city and state revenue and jobs.

With the PAS research concluded with newly suitable areas ranked into 3 levels of suitability (suitable, more suitability and most suitable) with increasing distances, violated stores can be relocated to these newly suitable areas without a penalty and also ensure that future retail stores comply accordingly. On the other hand, I would also recommend that the future land use designations for the vulnerable places (schools, licensed childcare centers, etc.) in undeveloped land areas should be taken into consideration while enforcing the distance separations stated in retail marijuana legislation. This recommendation will protect against any future violation of the legislative requirements.

Taking an early action as a contingency response strategy to provide a period of grace for non-compliant stores until their business permit expires and then enforce relocation on the new permit. Providing penalties will expedite the relocation of non-complaint stores to the recommended suitable areas. In addition, I also make another recommendation that the city of Denver should adopt this model for evaluating all future marijuana store locations, and their compliance with the law. The costs for implementing the model should be included in the costs of licensing and taxing existing and future stores.

Strength and Limitations of the Project

One of the strengths of the PAS research is that the use of GIS suitability analysis, which is sequential, analytical and repetitive through the geoprocessing modeling framework, measures the compliance rate and relative usefulness of land for the purpose of situating retail marijuana stores. GIS suitability analysis acts like sieve mapping to visualize all factors and constraints simultaneously. GIS suitability analysis eliminates the areas with constraints and ranks suitable areas in order to determine compliance and suitability.

Another strength is the use of GIS raster analysis with the AHP procedure which makes the analytical task of combining, overlaying and extracting information simultaneously from many data layers efficient and more quickly than its vector data format counterpart. The use of the ‘minus’ tool from spatial analyst to extract road areas (by subtracting the merged parcel areas from the city limits shape) offered more quality to the analysis since stores cannot be located on roadways. The road area was used as constraints to eliminate areas that are neither suitable nor compliant, thereby assuring and controlling the quality of the information products in the final map.

The limitation of the PAS is the exemption of drug or alcohol treatment facilities from my distance analyses due to lack of data from credible sources on their exact treatment locations. The ‘drug or alcohol treatment facilities’ spatial dataset are not listed in the Denver open data catalog. The ‘drug or alcohol treatment facilities’ spatial dataset should be incorporated in any future work regarding GIS suitability as it is a required consideration of Denver’s retail marijuana licensing requirements.

Dissemination Plan

I intend to share the PAS research deliverables and the report with the Office of Marijuana Policy – EXL, City and County of Denver. The plan will reflect any change request such as a corrective action to exclude drug or alcohol treatment facilities from the list of datasets. The retail marijuana store owners should be informed regarding the study. A stakeholder meeting should be organized to discuss the findings and deliberate on where the risk of non-compliance can be mitigated. A project timeline, cost, and other resources should be strategized to increase the compliance rate using the PAS findings.

Summary and Conclusion

The use of the statistical and GIS tools has provided an investigative power in this applied research to evaluate and recommend restoration of compliance by the Denver marijuana business community. The identified lapses in compliance to licensing regulations can be attributed to the lack of enforcement by city licensing and zoning officers in relation to enforcement of distance restrictions of recreational marijuana stores identified in the city code. Using my PAS research, non-compliant stores have been identified for relocation or sanctioned grandfathering to allow business continuation. Furthermore, future retail marijuana stores can be situated without violation of distance restrictions in relation to vulnerable locations if a revised zone distance of 650 feet were to be adopted and enforced. This PAS research has presented an evaluation with useful insight to encourage the city of Denver to examine and adopt new zoning distances for retail marijuana licensing in an effort to mitigate current zoning non-compliance and to encourage future application and verification of revised zoning requirement thresholds prior to issuing zoning approval and operating licenses.

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Tobacco/LawsRegulations

Appendix A: City of Denver Data Permission

Marijuana Distance Restrictions - Denver -GIS

Campbell, Bia - EXL OMP Marijuana Policy Analysis <Bia.Campbell@denvergov.org>
Thu 2019-07-18 11:26 AM
To: Aniekan Akpanekong <aniekan.akpanekong@waldenu.edu>

Here are some resources that might be helpful – we use this language to help applicants navigate the rules. :

There are some resources that are available that can assist an applicant:

- A reliable source for child care establishments can be found here as this provides child care establishments both in and outside of Denver.
- Recreation centers and pools can be found on Denver's Open Data Catalog.
- Zoning information for a specific address can be found using this map.
- Additionally, public property can found through this dataset on Denver's Open Data Catalog Denver's Open Data Catalog (you have to look at the file and identify the owner).

It is the responsibility of the applicant to review the location for eligibility. EXL will complete an analysis of the spacing requirements and the eligibility of the location once an application is submitted.

And this is from our website under Acceptable Facility Locations:

Proposed facility locations must comply with the restrictions laid out in the Denver Zoning Code, the Former Chapter 59 Zoning Code, and the Denver Revised Municipal Code.

The Marijuana Facility Location Guide has been put together to assist applicants in choosing an acceptable location.

- The map at the bottom of this webpage displays active medical marijuana center and retail marijuana store licenses.

A list of pending marijuana applications can be found on the Denver Open Data Catalog.

A list of proposed locations for pending medical marijuana center and retail marijuana store transfer of locations can be obtained by e-mailing marijuanainfo@denvergov.org

A list of active Denver child care facility licenses can be found on the Denver Open Data Catalog.

A list of all licensed childcare facilities in Colorado, including preschools, can be found on the Colorado Office of Early Education website under Licensed Facility List.

Additionally, you can find the zone districts surrounding a proposed location using this map.

Please Note – The criteria for successfully completing a transfer of location have recently changed with the passage of Council Bill 16-0291. We strongly recommend that you seek legal counsel to ensure compliance with the law.

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