

High-Speed Railway from Los Angeles to Las Vegas: An Accessibility, Least-Cost Path and
Cost-Distance Analysis Using G.I.S.

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Abstract

Geospatial technology is a useful tool when identifying land corridors for transportation networks. The primary existing transit corridor between Los Angeles, CA and Las Vegas, NV is Interstate-15, approximately a four-hour automobile trip without traffic. Virgin Trains USA LLC is proposing a high-speed railway connecting Las Vegas and Victorville, CA to provide an alternative means of travel to the interstate road system. This study uses least-cost path analysis to propose an alternative corridor for the high-speed railway being constructed along Interstate-15, between Victorville and Las Vegas. The proposed least-cost path is evaluated by its cost, safety, and efficiency as an alternative to Virgin Trains' proposed high-speed railway. Subsequently, this paper discusses the change in Los Angeles' road and rail system facilitated accessibility to Las Vegas, that will occur with the future inclusion of Virgin Trains' new high-speed railway along Interstate-15. Previous least-cost path and accessibility studies are referenced to justify the methodology for proposing an alternative high-speed railway corridor and evaluating the system facilitated accessibility changes within ArcMap. Once the Virgin Trains' high-speed railway corridor is constructed, Los Angeles County's system facilitated accessibility to Las Vegas will improve significantly where access to the existing railway systems are present.

Keywords: accessibility, GIS, corridor, least-cost path analysis, geospatial, transportation

Contents

1.) Introduction.....	4
a.) Study Area.....	5
b.) Least-Cost Path Corridor Criteria.....	9
c.) System Facilitated Accessibility Criteria.....	10
2.) Literature Review.....	11
a.) Analytical Hierarchy Process.....	11
b.) Least-Cost Paths in GIS.....	19
c.) Defining Accessibility.....	22
3.) Data Collection and Formatting.....	27
a.) Least-Cost Path Data.....	28
b.) System Facilitated Accessibility Data.....	33
4.) Software & Hardware.....	40
5.) Analysis.....	41
a.) Least-Cost Path Analysis.....	42
b.) System Facilitated Accessibility Analysis.....	53
6.) Results.....	58
7.) Discussion & Conclusion.....	63
8.) References.....	67

1.) Introduction

In this study, Esri's ArcGIS for Desktop (ArcMap) software is employed to accomplish two objectives. First, propose an alternative least-cost path for the construction of a high-speed electric railway (HSR) project connecting two locations – Victorville, CA and Las Vegas, NV. Second, visualize the current and future state of Los Angeles (LA) County's system facilitated accessibility to Las Vegas with the anticipated Virgin Trains (VTUSA) HSR. Geographic information systems (GIS) have the ability to contribute to the analytical process of planning and decision making for these objectives. In planning and development of public transit infrastructure, GIS, and the utilization Multi-Criteria Evaluation (MCE) procedures, e.g., Analytical Hierarchy Process (AHP), assist in the process of informed planning and decision making. "MCE is a procedure which enables people to make the most appropriate choice among many criteria" (Bera et. al., 2016). Spatial analysis coupled with analytical MCE models are often selected and designed to help transportation planners solve complex problems by rating decision criteria and alternatives in a GIS (Cathcart et. al., 2013). Other terminology (e.g., Multi-Criteria Decision Making, Multi-Attribute Decision Making, etc.) has been used to describe these same processes, however MCE is used here.

The proposed least-cost path (LCP) for the HSR is built using ArcMap's Spatial Analyst Cost Path (*Spatial Analyst: Cost Path*) tool and require an accumulated cost surface to output a corridor between an origin and destination. Such a surface can be defined as a friction surface or representation of a landscape, which aggregates the varying costs incurred on an entity that traverses it. This study considers "least-cost" as a generalized term expressing three criteria (cost, efficiency, and safety), of which their sub-criteria are weighted as individual cost surfaces and overlaid to create an accumulated cost surface using ArcMap's *Spatial Analyst: Weighted*

Overlay tool. Here, the system facilitated accessibility of LA County's roadways is also analyzed to compare against VTUSA's new HSR as an alternative method of traveling to Las Vegas. LA County's accessibility to Las Vegas will be explored in this study and defined in terms of system facilitated accessibility, wherein it measures an entity's ability to get to a destination within a transportation network and the associated effort in making the trip (Church & Lei, 2010). The new HSR will undoubtedly change the level of system facilitated accessibility LA County has to Las Vegas. ArcMap's *Network Analyst* toolbox and various Python scripting methods are utilized to create a transportation network dataset (hereafter, network dataset) synthesizing impedances like time, monetary expenses, and distance as variables for a system facilitated accessibility equation and metric.

a.) Study Area

VTUSA and Fortress Investment Group have recently launched Brightline in Florida, the United States' first privately financed intercity passenger rail within a century (Crooks & Varghese, 2019). More recently, VTUSA has begun the process of securing approval and resources to construct a new HSR between the Las Vegas and the Victorville (Figure 1).

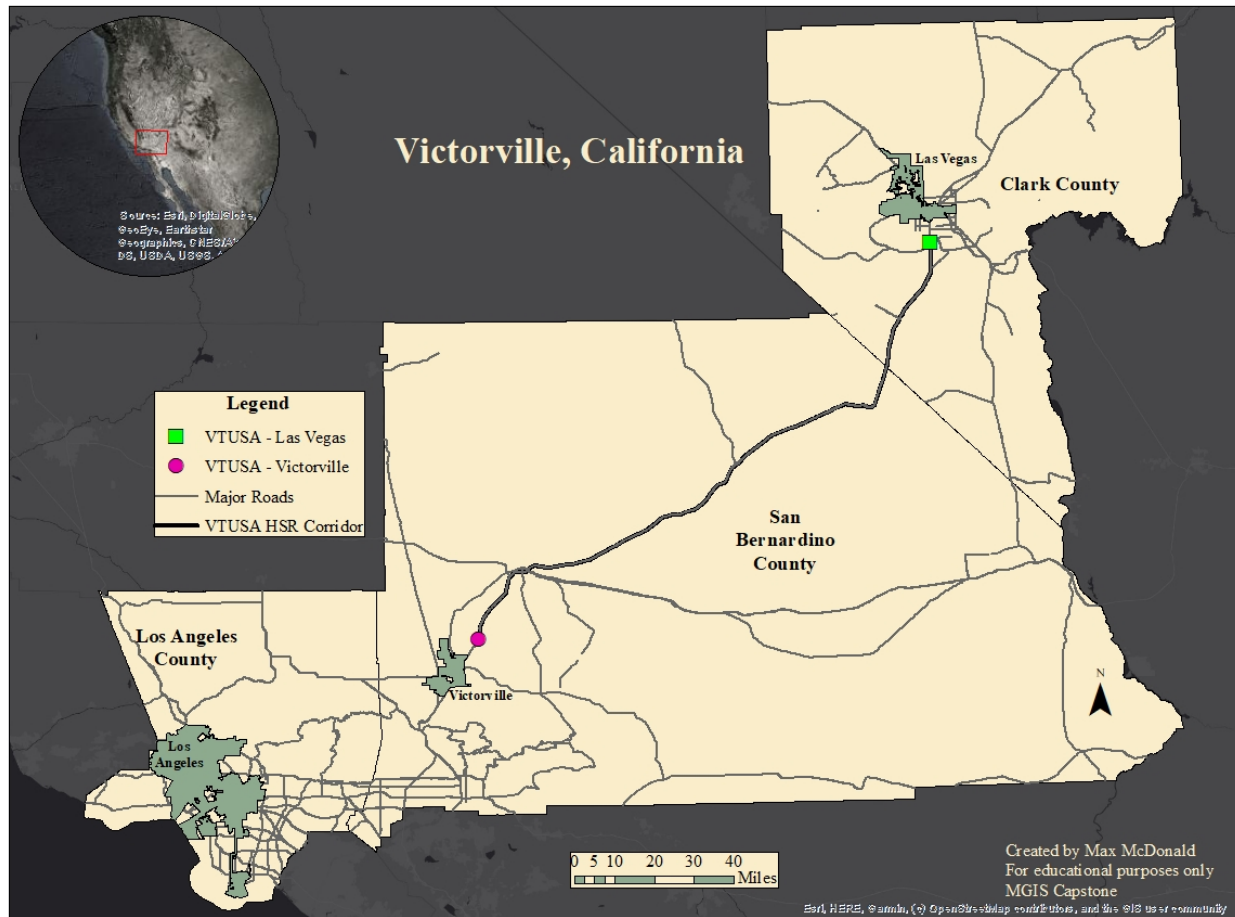


Figure 1 - Victorville, the first of three VTUSA proposed stops into California.

Pending U.S. Federal Railroad Administration (FRA) approval, the VTUSA proposed HSR will be constructed along Interstate-15 (I-15) and aims to begin transporting passengers in 2023 (Cogley, 2020). VTUSA is proposing to build a new station in Victorville southwest of the intersection of Dale Evans Parkway and I-15 (Varshney, 2019). The HSR will travel 90 minutes, non-stop from Victorville to a contracted location along Las Vegas Boulevard across from the Las Vegas South Premium Outlets (Martin, 2020). VTUSA's proposed station location in Victorville lies approximately eight miles (as the crow flies) northeast of the existing railway station on Amtrak's Southwest Chief, while the proposed Las Vegas Station is planned to be built approximately three miles southwest of McCarran International Airport. The eventual 170-

mile HSR will cost approximately \$4.8 billion and is primarily being funded via the California Infrastructure and Economic Development Bank, who have contributed a tax-exempt, fixed-rate revenue bond of \$3.2 billion (Martella, 2020). At the time of writing, no estimate of passenger costs or ticket price has been established for the new HSR. In October, 2019, Bob O'Malley of VTUSA said in a presentation to the Nevada Clark County Board of Commissioners that the initial project will aim to connect Las Vegas to Victorville, with plans to eventually extend other stations to Palmdale, CA and Downtown LA (Las Vegas Review-Journal, 2019).

How does one rationalize the creation of a new HSR in the first place? Considering the volume of rail ridership in the U.S., specifically HSR-travel, the VTUSA venture is supported by ridership increases. Railways that connect to Union Station in LA are permitted to transfer to Amtrak's Southwest Chief railway and reach the proposed VTUSA HSR with a short transfer distance between the two stations. According to the American Public Transportation Association's (APTA) annual ridership totals report (of heavy, light, and commuter rail types), over 4.8 billion records of riders were recorded in 2019. The year showed a 66% increase from almost 2.9 billion riders in 1990 (APTA, 2019). In 2019, LA City Metro rail systems (considered as a commuter rail by the APTA), reported an average of over 23,000 week-day (Monday – Friday) riders, roughly 1.2 million city metro riders a year, not including weekends (2019). The LA City Metro rail system is comprised of the Blue, Red, Purple (sometimes referred to as D-Line), Green, Gold, and Expo railways, and eventually will be able to connect to the Las Vegas-bound HSR (via Union Station and Amtrak railways), and the demand for ridership opportunities in LA City will help drive the new VTUSA project. However, other commuter railways exist within LA County as well. These include commuter rail systems also with direct connections to LA Union Station. LA County's Metrolink owns and operates railways such as Antelope Valley,

San Bernardino, Riverside, & Ventura County. Metrolink railways (2020) recorded approximately 93.1 million riders in the year of 2019. Amtrak recorded 11.5 million riders in California on their primary railways, which includes the Southwest Chief railway (RPA, 2020). Figure 2 displays the current system of the three aforementioned rail systems (the city Metro, Amtrak, and county Metrolink) that will facilitate access to Victorville for LA County.

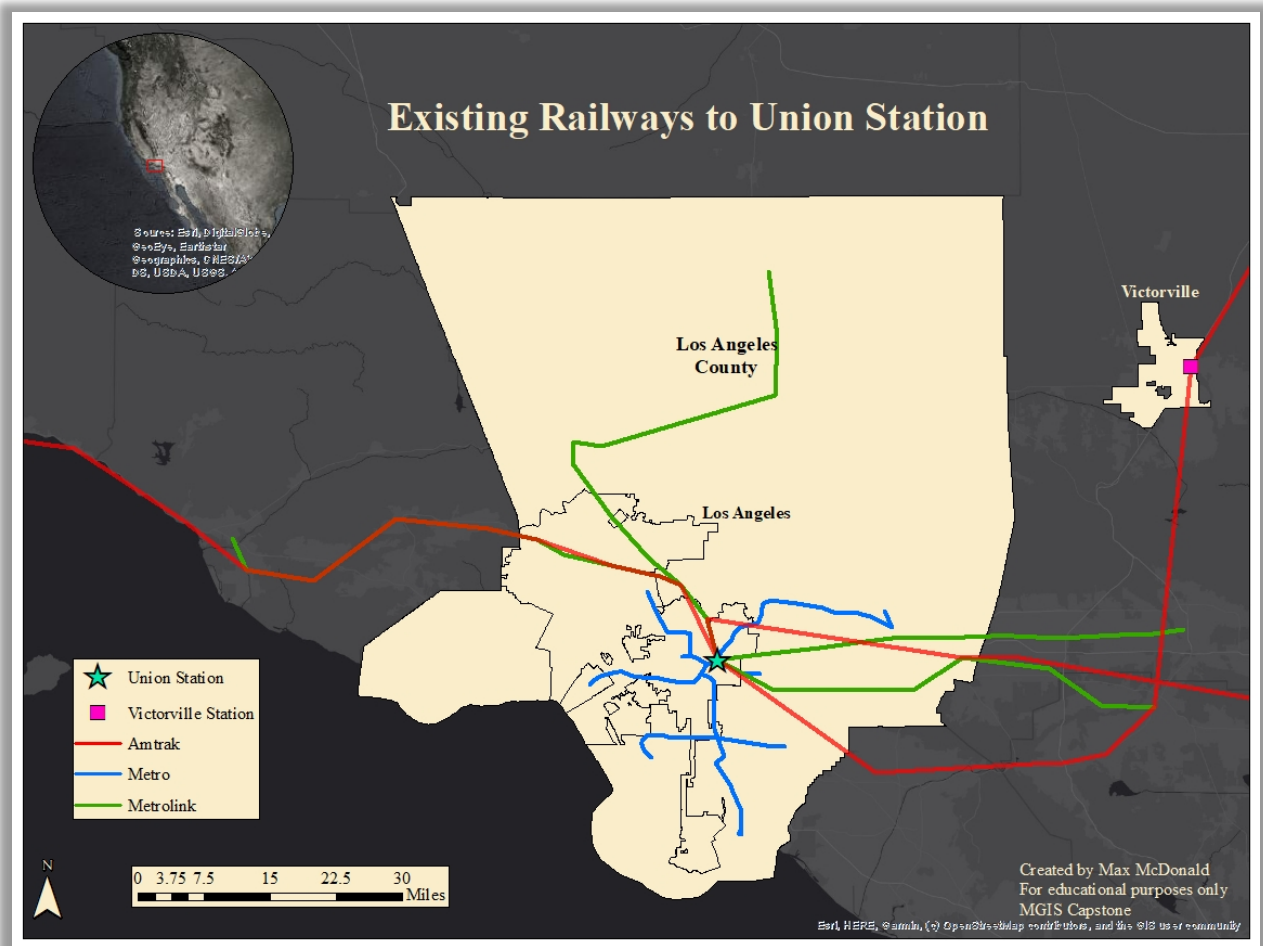


Figure 2 – LA County rail systems connecting to Union Station, L.A. Created in QGIS with geocoded station addresses.

b.) Least-Cost Path Corridor Criteria

This study examines the VTUSA proposed HSR being constructed along I-15. Through LCP analysis (LCPA) this study proposes a HSR corridor that aims to shorter in length, more efficient, and safer to the public.

Directness & Efficiency

Is the construction of a HSR along I-15 the most direct choice compared to other corridor options that can be derived by spatial analysis? Can a more direct path that considers the above questions be visualized in order to reduce costs of construction? Does VTUSA's HSR corridor consider the area's land use, elevation, and topography to minimize the distance travelled? In terms of safety, does the proposed HSR maintain a safe distance from critical infrastructures like hospitals, airports, electrical substations, power plants, active mines, and public schools? A HSR should traverse a corridor that maximizes efficiency, thereby justifying its cost as well as reducing future costs by considering the safety related topics that are inherent in its transportation applications.

Safety

How safe is the construction of a HSR along this corridor? A primary criterion for this study's alternative LCP is the safety of those near the HSR; anyone that can be injured or killed in the event of an accident. This study's motivation for proposing an alternative LCP is found in the safety-related accidents/incidents reported by the FRA. The FRA divides accidents/incidents into three categories: (a) "train accidents", or safety-related events involving rail equipment, (b) "Highway-rail grade crossing incidents", wherein an impact between a rail and highway user (pedestrian or non-pedestrian) occurs, and (c) "other incidents" described as any death, injury, or

operational illness of a railway employee that is not the result of the first two categories (n.d.). In the first accidents/incident's category (Highway-rail grade crossing incidents), the U.S. averaged 2.52 deaths per-year, per million miles of railway travelled on Amtrak and commuter railways from Jan. 2011-Feb. 2020 (FRA, 2020). Within the same reporting period and accident/incident category, per-year death and injury tolls in the U.S. averaged at 73.2 and 217.2, respectively (FRA, 2020). Again, in the same period and accident/incident categories, Florida's per-year tolls averaged to 7.8 deaths and 23.3 injuries, while California recorded 21.5 and 45.7, respectively (FRA, 2020). If the VTUSA proposed HSR does not intend to cross I-15 at all, it is still possible for it to cross other road types or even derail (an accident/incident categorized by the FRA as "train accidents"). From Jan. 2011-Feb. 2020, the FRA reported a per-year average toll of 56.4 commuter-rail derailments in the U.S., and an average of 2 and 3.4 in Florida and California, respectively (2020).

c.) System Facilitated Accessibility Criteria

It is important to measure accessibility provided by transit networks to support the process of transit planning and decision making (Church & Lei, 2010). The second objective of this study aims to visualize the change in system facilitated accessibility a new HSR will provide LA County residents when traveling to Las Vegas. Regardless of the chosen HSR corridor, how is a new HSR justified? The connectedness of cities and their people can contribute to the economic growth patterns of those regions and a nation as a whole. Supply of a region's railway services is distinct, it is not nearly continuous like a roadway network, therefore the spatial allocation of railway stations directly impact the distribution of population as well as interacts with the level of road congestion, depending on some degree of the spatial structure of the railway network (Dröes & Rietveld, 2015). Will VTUSA's HSR increase the system facilitated

accessibility of those it aims to connect, and can GIS help stakeholders visualize this? The construction of a GIS network dataset in this study will assist in solving the most efficient routes between 2,345 census tract origins in LA County to one final destination in Las Vegas, thus creating a system facilitated accessibility index to measure the change in system facilitated accessibility between present and future states of the LA County transportation road and railway networks.

The next section that follows (section 2) is a literature review summarizing the relevant studies that contribute to the analysis presented thereafter. Section 2 addresses the more detailed aspects of the methodology to create a single alternative LCP and measure facilitated system accessibility. Section 3 will discuss the data collected and formatted for the analysis, which includes any pre-processing preparation of the data. Section 4 will summarize the software and hardware utilized for the analysis and section 5 will present the analysis workflow itself. Following, section 6 will present the results of this study and contextualize the major findings. Finally, section 7 will discuss challenges and limitations present as well as how the application of geospatial technology contributes to its' field and the responsibilities of transit infrastructure planning and decision making.

2.) Literature Review

a.) Analytical Hierarchy Process

The use of GIS as a tool for informed decision making is demonstrated in many fields of focus. This study represents the use of GIS, and the MCE technique AHP to formulate an informed methodology in generating an alternative LCP corridor for VTUSA's new HSR. Within the geospatial-analysis context, MCE is commonly performed to create accumulated cost

surfaces by incorporating techniques such as AHP or Weighted Linear Combination (WLC) (Chow et. al. 2015). AHP has been employed to reduce complicated decision stages to a series of comparisons by taking in the necessary criteria, considering their alternatives, and achieving the best solution (Aydun et. al., 2019). “AHP is a multi-objective, multi-criteria decision-making approach, which enables the decision maker(s) to arrive at a scale of preference drawn from a set of alternatives” (Dehghani et. al., 2015). Using GIS, AHP has been used in site selection analysis (see Höfer et. al, 2016; Júnior et. al. 2011; Uyan, 2013), habitat corridor modelling (see LaRue et. al., 2008; Gao et. al., 2020) as well as the routing of HSRs (see Bediroglu & Yildirim, 2019) and other linear engineering structures (see Atkinson et. al., 2005; Bagli et. al., 2011).

The Calculations of Analytical Hierarchy Process

The utilization of AHP involves a series of calculations that begins with the use of a pairwise comparison matrix (PCM). Figure 3 represents a simple worked example of a PCM that evaluates four criteria (represented by the red numbers 1, 2, 3, & 4). Cells are ranked here to represent importance, or unimportance, when compared against another criterion. In Figure 3, for example, decision makers of this sample PCM rank criterion four as two times more important than criterion one. Therefore, criteria one is one-half (.50) as important (or less important) as criterion four.

Constructing a PCM is a method comparing two objects (decision criteria and decision alternatives) at once, rather than decision makers comparing several objects at once, and results in an aggregate best-choice hierarchy, relating to the best perceived criteria (Krejčí, 2018). The formation of a PCM is usually the product of multiple expert/stakeholder knowledge and opinions.

	1	2	3	4
1	1	0.50	0.33	0.50
2	2.00	1	0.50	0.50
3	3.00	2.00	1	2.00
4	2.00	2.00	0.50	1

Figure 3 - Example PCM (Aydun et. al., 2019).

A key theme in literature has been the use of a PCM to compute and assign weights for criteria and their alternatives. In this study, AHP is employed to assign spatial weights for input to the ArcMap's *Spatial Analyst: Weighted Overlay* tool when calculating an accumulated cost surface for LCP creation. PCM creation is only the first step in AHP. As described below, PCMs contribute to the valuation of criteria weights. From the most rudimentary standpoint, this study's attitude is that the best HSR-LCP will be the corridor that incorporates the criteria of cost, efficiency, and safety. The sub-criteria of cost, efficiency, and safety will be weighted in a PCM during AHP. It is important to note that the hierarchical evaluations of spatial weights here will be attributed to common knowledge and relevant literature, representing a proof-of-concept study. Regardless, PCM construction will not be consulted and produced by multiple experts/stakeholders, but rather produced via multiple PCMs, each favoring a particular criterion, and then averaged together to create a best-attempt at a realistic PCM that would have normally been determined by experts/stakeholders for a HSR-LCP construction (see section 5).

Besides producing criteria weights for the inputs of an LCP, engaging a PCM helps establish a consistency ratio (CR) for the pairwise comparison rating of criteria as a hierarchy.

Introduced by Thomas Saaty in 1980 (see *The Analytical Hierarchy Process: Planning Priority Setting, Resource Allocation*), the AHP theory of measurement aims for a consistent ranking of criteria measured by the CR. The CR measures the ratings in the PCM to conclude how close they are to randomness in assignment. “When the CR in a PCM exceeds 10%, the judgements often need to be reexamined (Saaty, 1987). The inputs into the PCM directly determine the CR that evaluates them, and random ratings need to be retested or repeated. Similarly, for the criteria weights, the CR is equated after completing the PCM, during a later step in AHP.

The creation of a PCM to produce criteria weights, and a CR which evaluates them, is not as straightforward as the single matrix in Figure 3. The AHP is a multi-step process that produces the criteria weights they are seeking well before the CR is produced at the end. Furthermore, the PCM is usually filled out with a larger scale of ratings (Table 1) than those used in Figure 3, which only uses a one-to-three scale rating. The fractional values in Table 1 are more easily handled when converted to decimals for mathematical purposes.

Table 1 - An in-depth scale of importance for criteria in a PCM.

9	<i>Extremely more important</i>
8	<i>Far - Extremely more important</i>
7	<i>Far more important</i>
6	<i>Much - Far more important</i>
5	<i>Much more important</i>
4	<i>Slightly - Much more important</i>
3	<i>Slightly more important</i>
2	<i>Equal - Slightly more important</i>
1	<i>Equal</i>
1/2	<i>Equal - Slightly less important</i>
1/3	<i>Slightly less important</i>
1/4	<i>Slightly - way less important</i>
1/5	<i>Much less important</i>
1/6	<i>Much - Far less important</i>
1/7	<i>Far less important</i>
1/8	<i>Far - Extremely less important</i>
1/9	<i>Extremely less important</i>

A Mock AHP Example

Listed below are the seven steps and a worked example that are required in AHP to produce the criteria weights that are needed to derive the CR:

1. Establish a PCM of criteria (e.g., cost, safety, and efficiency) for a problem (Table 2).

Compare each criterion from row to column and establish which is more or less important and assign a rating (Table 1). Criterion on a given row that are valued equally to the corresponding criterion on a column are assigned a value of one. Other ratings are assigned based on stakeholder/expert opinion/input. The inverse relationship of two criteria are represented by the inverse of the first value assigned to their relationship. For example, if criterion one is five times more important than criterion two, then criterion two is one-fifth as (less) important than criteria one. When the ratings are finished, sum

the criterion by their columns. Make a note of the total number of criteria (*n*) as this number will be used in later steps.

Table 2 - AHP Step 1: Pairwise comparison matrix for three criteria.

Pair Wise Comparison Matrix			
	Criterion 1	Criterion 2	Criterion 3
Criterion 1	1.000	5.000	3.000
Criterion 2	0.200	1.000	7.000
Criterion 3	0.333	0.143	1.000
Sum	1.533	6.143	11.000
Total Criteria (<i>n</i>)	3		

- Next, one normalizes the PCM by dividing each cell by the sum of each criterion column. In other words, every cell in criterion one’s column would be divided by 1.533, 6.143 for criterion two, and 11 for criterion three of Table 2 (for results, see Table 3). These normalized values are then summed by their Table 3 criterion row and divided by *n*. For example, the criterion weight (*CW*) for criterion one would be 58%, represented by the equation:

$$CW_1 = (0.652 + 0.814 + 0.273) / n \tag{1}$$

Table 3 - AHP Step Two: Normalized Pairwise Matrix & Criteria Weights.

Normalized Pairwise Matrix				
	Criterion 1	Criterion 2	Criterion 3	Criterion Weight (<i>CW</i>)
Criterion 1	0.652	0.814	0.273	0.580
Criterion 2	0.130	0.163	0.636	0.310
Criterion 3	0.217	0.023	0.091	0.111

3. After the criteria weights have been determined (those that would be inputted into the *Spatial Analyst: Weighted Overlay*), the CR has yet to be established and requires creating a weighted sum value matrix (Table 4). Each criterion comparison cell in the PCM (Table 2) is multiplied by the criterion weight in the normalized PCM (Table 3) by row. Following this, each criterion row for Table 4 is summed to produce a weighted sum value (WSV) for each criterion. For example, the weighted sum value for criterion one (CW_1) would equate to 5.22, and is represented by the equation:

$$WSV_{CW1} = (1 * 0.580) + (5 * 0.580) + (3 * 0.580) \quad (2).$$

Table 4 - AHP Step Three: Weighted Sum Value Matrix

Weighted Sum Value Matrix				
	Criterion 1	Criterion 2	Criterion 3	Weighted Sum Value (WSV)
Criterion 1	0.580	2.900	1.74	5.22
Criterion 2	0.062	0.310	2.170	2.542
Criterion 3	0.070	0.016	0.111	0.197

4. Next, one creates a table representing each criterion's weighted sum value divided by their respective criterion weight (Table 5).

Table 5 - AHP Step Four: Weighted Sum Value divided by Criterion Weight

Weighted Sum Value / Criterion Weight		
Criterion 1	9	(5.220 / 0.580)
Criterion 2	8.2	(2.542 / 0.310)
Criterion 3	1.8	(0.197 / 0.111)

5. Next, one calculates the lambda (λ) max. This is done by summing the values in Table 5 and dividing them by n . In this example, λ_{\max} is 6.33 represented by:

$$\lambda_{\max} = (9 + 8.2 + 1.8) / n \quad (3).$$

6. The next to last step consists of the AHP user calculating a consistency index (CI). The consistency index of pairwise comparison ratings is evaluated in contrast to ratings given at random. In this mock example, CI equates to 1.67, represented by the equation:

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (4).$$

7. Finally, using Saaty's (1980) CI table for random judgements (Table 6), one calculates the CR by dividing the CI by the corresponding index for random judgements based upon the number of criteria (n).

Table 6 - AHP Step 7: Determining the CR.

n	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In this mock example, the CR would equate to 2.88, represented by the equation:

$$CR = (CI / RI_n) \quad (5).$$

As stated earlier, a CR exceeding 10% dictates that the pairwise comparison judgements are not consistent, and closer to a randomly inputted set of values (Saaty, 1987). In the mock example provided above, a CR of 288% is determined. While the pairwise comparison of criteria is extremely random by Saaty's standards, the example is only utilized as a demonstration of the AHP process that will be employed in this study. Usually, a CR of .20 (20%) is an acceptable result depending on the circumstances of the analytical problem (Saaty, 1987). Again, the values inputted into the PCM are often the averaged result of multiple experts and stakeholders relevant to the AHP-evaluated problem. The utilization of expert and stakeholder knowledge and opinions often results in a CR sufficient in regard to the criteria. Although here, again for

clarification, AHP will be replicated in a proof-of-concept exercise that employs multiple pairwise comparisons favoring each criterion. Instead of one PCM, five matrices will be utilized in this study. Each matrix is a representation of an unique stakeholder or expert favoring the sub-criteria (Figure 4) of cost, safety, and efficiency. The five matrices will be averaged together, cell-by-cell, to create a consensual PCM.

Of note is this study is constrained by the availability of public data, which directly influences the chosen sub-criteria categories that are depicted in Figure 4. In the respective sub-criterion matrices for this study, the sub-criterion being favored will always rate as more important against the other four alternatives.

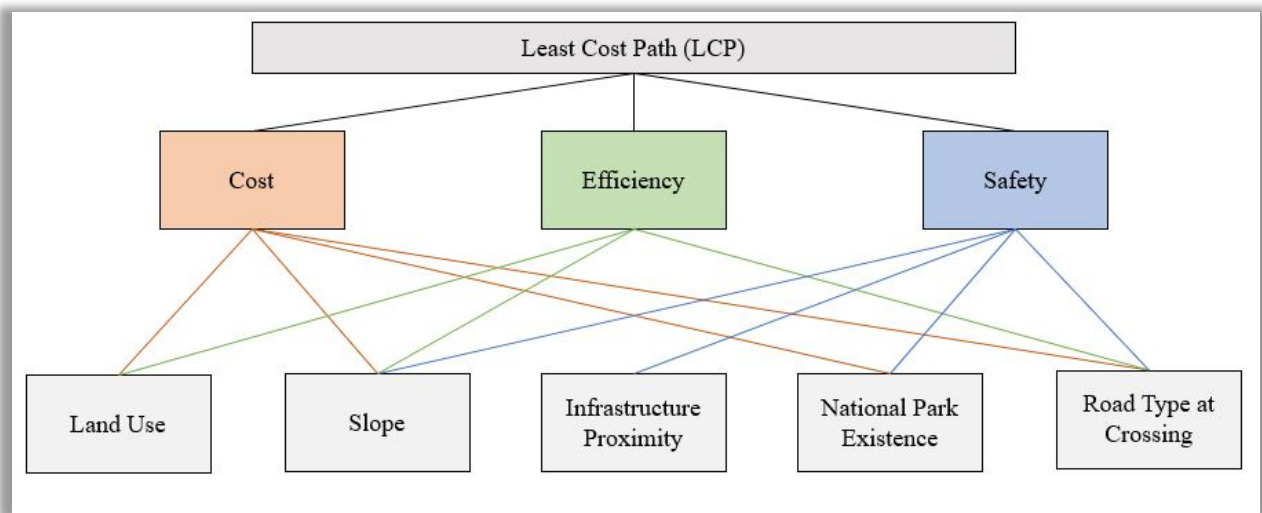


Figure 4 – Sub-criteria influencing the proposition of a LCP to contrast against VTUSA's proposed corridor.

b.) Least-Cost Paths in GIS

In a GIS context, LCPA can be conducted with vector or raster data. Although, continuous raster surface is the more commonly chosen format for LCPA and is the chosen

format in this study. On a cell-by-cell basis the LCP is constructed from a source (origin) cell examining each neighboring cell on a cost (or friction) surface to provide a path that accumulates the least amount of cost to its given destination cell. A continuous raster cost surface defines how expensive movement through each cell is rated (Bagli et. al., 2011). Expense is a vague term that does not have to refer to monetary costs. In LCPA, cost is a single expense or an accumulation of multiple expenses. This study's three general criteria of cost, efficiency, and safety have their sub-criteria weighted through AHP and will determine the accumulated cost surface used in LCP construction.

Cost of movement over a landscape can be discussed in the context of networks, such as roads, using maximum allotted speeds or travel time measurements, or in the subject of drainage studies where slope and aspect values of a digital elevation model (DEM) are considered as costs affecting water flow direction and accumulation (Douglas, 1994). Certain GIS software modules employed for the creation of LCPs, such as IDRISI's *r.drain* module, are created for hydrological purposes and the lower value between adjacent cells is sought, causing the path to terminate when the lowest overall value is reached, even if that cell is not the destination intended (Doneus et. al., 2007). For this reason, hydrological modules are not best suited in the creation of linear engineering networks and this study chooses to use ArcMap (v. 10.8) and its *Spatial Analyst* because of its strengths in computing isotropic and anisotropic movement across an accumulated cost surface.

AHP-weighted, accumulated cost surfaces in Esri's ArcGIS software have been used to model drug trafficking corridors to the U.S. border from Mexico. Chow et. al. (2015) predicted ground-based drug trafficking corridors for transporting marijuana and opium derivatives using physical, socio-demographic, and drug violence data to construct a cost surface. Using ArcGIS

software in Italy, Bagli et. al. (2011) utilized MCE derived cost surfaces to suggest LCPs for power lines with landscape, human health, and nature factors as their cost criteria. ArcGIS software and AHP techniques were combined in Turkey to evaluate LCP criteria for a pipeline route (Aydun et. al., 2019) and the authors weighted topography, restricted areas, ridges, slopes, rivers, streams, terrain, industrial areas, and roads through a PCM. Again, using ArcGIS software, Bediroglu & Yildirim (2019) decreased generalized costs of a Turkish HSR project by 12% implementing a pairwise comparison of eight criteria.

It is important to create an LCP and visually contrast it with known or planned routes, however it is more important to quantifiably evaluate paths side-by-side in terms of their generalized costs and overall lengths. VTUSA's has hinted to the idea in an economic development plan/presentation to the California Debt Limit Allocation Committee that their proposed HSR will be along I-15 (Varshney, 2019). Unlike their proposed stations, it is unknown where their HSR will lie exactly, thus, I-15 itself will be utilized as a representation of the VTUSA's proposed HSR in this study to contrast against this study's alternative LCP.

Methods for comparing and contrasting corridors are documented across many linear engineering structures, like roads, HSRs, pipelines, and power lines. Chow et. al. utilized Dijkstra's (1959) algorithm for calculating the LCP over roadway networks and not across a continuous landscape. Unfortunately, the author's overlaid the generated routes in 2010 with previous known routes from 2007, and only showed potential new deviation from known routes with no quantifiable way for evaluating the newly predicted routes. Bediroglu & Yildirim (2019) tested their final route for sensitivity by statistically examining the changes in relationships between the inputs and outputs of the model. This approach changes the cost criteria weights one at a time to observe the effects on the LCP (Daniel, 1973). By changing one criterion at a time,

all other criteria can be fixed to a baseline (Chen et. al., 2010). While the Bagli et. al. (2011) route design is not specifically constructed through AHP, the authors evaluation of the routes through iterative MCE evaluation in neutral, economic, human health, and socio-economic perspectives, offers a great example for determining the best generated LCP through altered weighted preferences. To do this, Bagli et. al. utilized weighted linear combination to combine the criteria weights (which slightly differed from the criteria used to establish the routes) to be tested and reported in a frequency table 2,000 times to determine how many times each path is ranked among each other (2011).

Aydun et. al. utilized a line-based cartographic simplification (LCBS) process on the new pipeline route and decreased the amount of vertex points in their LCP from 772 to 170, ultimately decreasing length at the expense of increased costs (2019). In linear engineering structure applications, it is desired/planned that the route has as few vertex points as possible to facilitate construction work (Aydun et. al., 2019). While the spatial weights assigned in this analysis will be evaluated by their consistency ratio, the final path will undergo an MCE similar to the Bagli et. al. method (2011) and judged based on the amount of cell cost categories it traverses, determined by ArcMap's *Spatial Analyst: Extract by Mask* tool, and its overall length. This is due to the overall objective of evaluating a railway corridor in terms of measuring its safety, efficiency, and cost, and not for the purposes of streamlining construction as suggested in Aydun et. al. (2019).

c.) Defining Accessibility

This study also aims to analyze the impact of VTUSA's new HSR in terms of the system facilitated accessibility LA County has to Las Vegas. There exists no formal established method of evaluating accessibility, and its definition will vary depending on its context of use. Kumagai

& Wachs (1973) define accessibility as “the ease (or difficulty) that opportunities (e.g. employment) or services can be reached from a location.” Cheah et. al. generally describe accessibility as the travel impedance in terms of travel distance or travel time between two locations (2012), but also point to the works of Penchansky & Thomas (1981) whom define access in terms of health care services as the dimensions of availability, accessibility, accommodation, affordability, and acceptability. Building on the concept that accessibility is not just a function of distance or travel time, Church & Lei integrate multiple studies to define six concepts of accessibility, such as: (a) system accessibility, (b) system facilitated accessibility, (c) integral accessibility, (d) space-time geography (see Hägerstrand, 1970), (e) utility theory, and (f) relative accessibility (2010). The latter of which (relative accessibility), explored by Church & Marston (2002), is based on comparing access between modes or types of users. If the consumer has a choice between using a personal vehicle and using public transport in travelling to a destination, the choice is made as a function of monetary cost, time, convenience, and safety (Church & Marston, 2002).

The accessibility analysis here is focused on evaluating the affect this study’s proposed LCP corridor induces between LA County and Las Vegas and contrasting it against the current level of system facilitated accessibility provided by the existing road and highway networks. Once again system facilitated accessibility is defined here as a measure of an individual’s ability to get to a destination within a transportation network (e.g., roads or railways) and the associated effort in making the trip (Church & Lei, 2010). How the effort is determined depends on the availability of the data and the application context (Church & Lei, 2010). While the LCP this paper proposes will be built and evaluated in terms of cost, efficiency, and safety, the VTUSA proposed HSR will be evaluated in terms of system facilitated accessibility, wherein the effort of

reaching Las Vegas is a function of line segment length through a transit network (road and railway distances), travel costs (gasoline usage per mile for cars and railway ticket prices), and time, determined by the speed limits on roads and highways as well as the top speed local railways (e.g., the City Metro) or HSRs can reach legally.

Between January 2010 to February 2020, the weekly average price of regular gasoline per gallon in California was \$3.45 (California Energy Commission, 2020). The road distance between Union Station in LA and McCarran International Airport in Las Vegas via I-15 is 263 miles and would take approximately 436 minutes (just over seven hours) by car (Google, n.d.). The Environmental Protection Agency (EPA) defines “light duty vehicle” as a vehicle with a gross weight rating below 8,500lbs (n.d.). Thus, based on average fuel efficiency statistics provided by the U.S. Dept. of Transportation, the average domestic and imported light duty vehicle (made between 2010 and 2017) would spend approximately \$25.35 and \$24.72 on regular gasoline travelling from Union Station to the McCarran International Airport (downtown Las Vegas), respectively (n.d.).

At the time of authoring this paper, VTUSA has yet to release information regarding the price of a one-way ticket from Victorville to Las Vegas, and ticket pricing information on Brightline’s website is temporarily closed down due to the COVID-19 pandemic (see Brightline, 2020). However, at the time of opening, Brightline was charging \$10 and \$15 for one-way tickets for their standard and more spacious coach seats, respectively (see Miami Herald, 2018; NBC6 South Florida, 2018). Therefore, the railway fare cost on this study’s LCP in the created network dataset will be set at \$20. On the 31st of July 2020, Amtrak would charge \$19 for a one-way coach (standard) ticket to Victorville from Union Station in LA and \$39 from Chatsworth, its furthest LA County station from Victorville (Amtrak, n.d.). Metro (n.d.) quotes a one-way

price of \$1.75 for any of their LA City lines connecting to Union Station. Table 7 shows the price of a one-way ticket from any of the four aforementioned LA County Metrolink railways at the furthest station location from Union Station, as of May 31st, 2020.

Table 7 - Most dollar amounts paid to reach Union Station on Metrolink Railways (Metrolink, n.d.).

Metrolink Line	Station Furthest from Union Station	One-way price to Union Station.
Antelope Valley	Lancaster	\$11.50
San Bernardino	Claremont	\$7.00
Riverside	Downtown Pomonca	\$9.00
Ventura	Chatsworth	\$9.50

As discussed earlier, the associated overall travel cost does not have to solely be a monetary function. In general terms, cost to travel through a transit system consider distance and monetary components of any journey along a network as a unified value (Barr et. al., 2015). The key benefit of the Barr et. al. (2015) approach to evaluating new transit infrastructure projects is the rapid appraisal of the effects on accessibility. Application of the Barr et. al. (2015) model to greater London shows that networks of different transportation modes can be analyzed over large spatial scales and reveals considerable spatial variability in transport costs and accessibility. While Barr et. al. (2015) employed their model for the advocacy of low-carbon transit methods, this paper's system facilitated accessibility study aims to only compare and contrast the changes in the existing systems facilitating travel from LA to Las Vegas (via Victorville and the VTUSA HSR) through a modified monetary cost, distance, and time equation inspired by Barr et. al.

Barr et. al., (2015) employs four steps in the measuring of accessibility of a group of geographical zones to a location. The process is briefly outlined below (Barr et. al., 2015):

1. Define geographical zones.
2. Build transportation networks.
3. Create a matrix of generalized costs within the transportation networks.
4. Use computed generalized costs to determine accessibility to destination of interest.

Generalized cost equations are defined in Barr et. al. (2015) by transportation modes. For private modes of transportation (e.g., driving a personal car), the equation is as follows (Barr et. al., 2015):

$$C_{PVT} = (V_{WK} * A) + T + D * [(VOC/occ) * VOT] + [(PC/occ) * VOT] \quad (6)$$

And for public modes of transportation (e.g., taking a bus or HSR), the equation is represented as (Barr et. al., 2015):

$$C_{PUB} = (V_{WK} * A) + (V_{WT} * W) + T + (F/VOT) + I \quad (7).$$

In Equation 7, V_{WK} is the disincentive weight for walking to an access point in a transportation network, A is the amount of time it takes to reach the access point, V_{WT} is the disincentive weight for waiting at an access point, W is the total amount of time waited for the journey to the destination, T is the total time spent on the journey, F is the fare or dollar amount spent on the journey, VOT is the value of time coefficient, D is the distance in kilometers, VOC is the vehicle operating costs per kilometer, PC is parking or other costs, and occ is the number of vehicle occupants.

In this paper, certain terms in the equations presented above are not being utilized, as this study focuses on monetary costs incurred, time spent on journeys, and distances travelled alone. Thus, wait times at access points will be ignored to create a simpler access model. Value of time

(VOT) will be higher for C_{PVT} costs (two, as compared to one) as people in a hurry are assumed to take travel matters into their own hands, rather than rely on public transportation modes.

Vehicle occupancy is at a fix setting of one (and could be modified in future studies). This is motivated by the paper's attempt to model the system facilitated accessibility at an individual level, as well as the fact that commuter carpooling in the U.S. has decreased from 19.7% in 1980 to 9.4% in 2013 (McKenzie, 2015). Disincentives for transferring between stations will not be factored into C_{HSR} transportation networks, as transferring between the Southwest Chief station and VTUSA proposed station is inconvenient, but necessary. Parking, or other costs (PC) (e.g., tolls) will be ignored as well due to the availability of public data. Therefore, the modified equation utilized here to measure system facilitated accessibility by each of LA County's census tracts (this study's geographical zones) to Las Vegas is represented for private (C_{PVT}) and HSR (C_{HSR}) as follows:

$$C_{PVT} = D + T * (VOC * VOT) \quad (8)$$

$$C_{HSR} = D + T * (F * VOT) \quad (9)$$

Where D is the total distance spent on the road or railway network, T is the total time spent on the trip, VOC remains as vehicle operating costs as well as VOT remaining as a value of time, and F remains as the fare cost incurred when travelling on a railway or HSR.

3.) Data Collection and Formatting

The spatial data utilized in this analysis can be categorized into two groups: primary and supplementary. Primary data is also useful for geographical reference but serves the main purpose of driving the development of an LCP or creating a network dataset for use in measuring present and future system facilitated accessibility. Supplementary data is collected here for map

production and geographical reference. This group of data consist of city or county polygons from sources such as the California Open Data Portal or the City of Las Vegas' Office of Geographical Information Systems Portal. It also includes shapefiles from the U.S. Census Bureau's TIGER/Line database and aerial imagery from the U.S. Geological Survey's (USGS) National Map database. All publicly available geographical data is procured as Esri shapefiles or Tagged Image File Format (TIFF) raster surfaces and stored in an Esri File Geodatabase (FGDB). This study uses the coordinate reference system "North American Datum 1983 HARN State Plane California V (FIPS 0405, in U.S. Feet)" for limited distortion and because the state plane zones usually follow county lines.

a.) Least-Cost Path Data

The study area for the LCPA is presented in Figure 5. In this analysis the LCP will be generated *from* VTUSA stations at Victorville and Las Vegas and the raster cell surfaces for these points are created within the FGDB. The first two required inputs for LCP creation include a source and destination cell, which are VTUSA's proposed station raster surfaces. Before being converted to raster formats, the two station points are arbitrarily "dropped" into the ArcMap project based on information VTUSA has released by way of press conferences, news stories, or meetings with county commissioner boards relative to the project. Until more accurate information is available, they serve as the origin and destination of this analysis' LCP. However, the accumulated cost surface, another required input for LCPA, does not rely on VTUSA information and is created with more reliable and accurate public data.

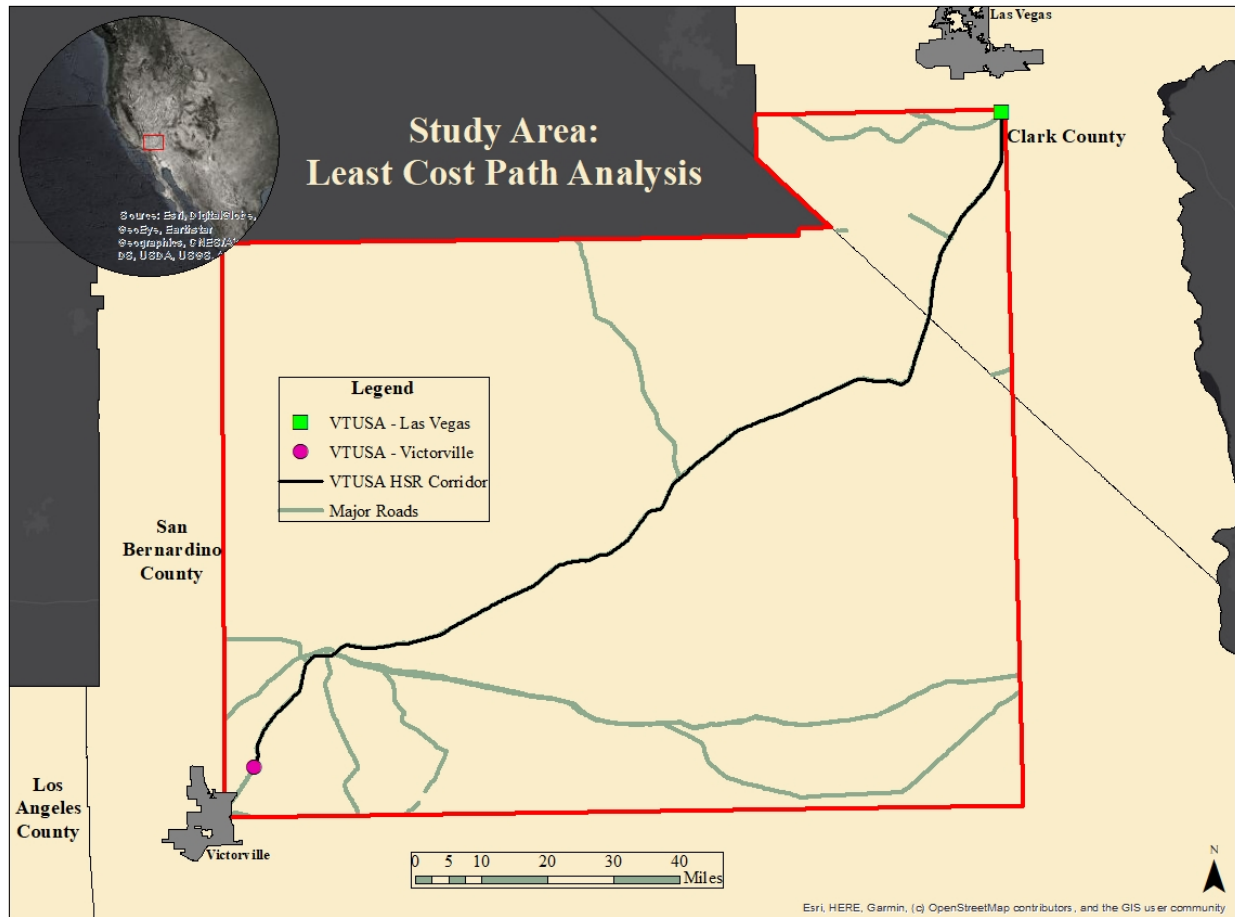


Figure 5 – The study area for creating an accumulated cost surface.

A subset of U.S. Census TIGER/Line road feature classes is extracted by the *Data Management: Select by Attribute* tool using the expression “[FULLNAME] = ‘I-15.’” The I-15 road feature class selection is split by the two VTUSA’s proposed station feature classes using *Data Management: Split Line at Point*, and saved as its own feature class “Interstate15_NE.” This new vector feature class represents the proposed corridor VTUSA will be building the HSR along (Figure 5) and used to compare and contrast this study’s proposed LCP corridor. The data chosen to represent the cost surfaces that the LCP will be derived from represent the sub-criteria of cost, efficiency, and safety (Figure 4). The shapefiles or raster data selected and prepared for the LCPA cost surfaces are summarized in Table 8 and are organized based upon their relationship to the

sub-criteria of the LCP. All raster data, or vector data to be converted to raster format, is calculated at 0.00035082774ft² (0.0004ft²), the smallest cell size of all the raster data collected, during pre-processing.

Table 8 - The publicly available data downloaded for the purposes of creating an accumulated cost surface in LCPA.

<u>Sub Criteria Relationship</u>	<u>File Name</u>	<u>Format</u>	<u>Cell Size or Feature Type</u>	<u>Coordinate System</u>	<u>Datum</u>	<u>Source</u>
Land Cover Land Use	NLCD_2016_Land_Cover_L48_20190424	Raster	30	Albers_Conical_Equal_Area	D_WGS_1984	USGS
Slope	USGS_12_n35-37w116-118.tif	Raster	0.00035082774	GCS_North_American_1983_HARN	D_North_American_1983_HARN	USGS
Road Type at Crossing	tl_2019_32003_roads.shp	Shapefile	Polylines	GCS_North_American_1983	D_North_American_1983	US Census
	tl_2019_06037_roads.shp	Shapefile	Polylines	GCS_North_American_1983	D_North_American_1983	US Census
	tl_2019_06071_roads.shp	Shapefile	Polylines	GCS_North_American_1983	D_North_American_1983	US Census
National Park Existence	nps_boundary.shp	Shapefile	Polygons	GCS_WGS_1984	D_WGS_1984	National Park Service (NPS)
Infrastructure Proximity	mineplant-f32003.shp	Shapefile	Points	GCS_North_American_1927	D_North_American_1927	USGS
	mineplant-f06071.shp	Shapefile	Points	GCS_North_American_1927	D_North_American_1927	USGS
	California_Power_Plants.shp	Shapefile	Points	GCS_WGS_1984	D_WGS_1984	California Energy Commission
	California_Electric_Substations.shp	Shapefile	Points	GCS_WGS_1984	D_WGS_1984	California Energy Commission
	Military_Airports.shp	Shapefile	Points	GCS_WGS_1984	D_WGS_1984	California Department of Transportation
	Public_Airports.shp	Shapefile	Points	GCS_WGS_1984	D_WGS_1984	California Department of Transportation
	Trans_AirportPoint.shp	Shapefile	Points	GCS_North_American_1983	D_North_American_1983	USGS
	Hospitals.shp	Shapefile	Points	WGS_1984_Web_Mercator_Auxillary_Sphere	Mercator_Auxillary_Sphere	Homeland Infrastructure Foundation
PublicSchools.shp	Shapefile	Points	GCS_WGS_1984	D_WGS_1984	US Department of Education & National Center for Education Statistics (NCES)	

In order to create an LCP for comparison to VTUSA’s corridor along I-15, a continuous raster surface is chosen as the inputted accumulated cost surface. Formatting the accumulated cost surface is the primary pre-processing stage for LCPA. Each sub-criteria relationship is formatted as its own individual cost surface to eventually be inputted into the *Spatial Analyst*: Weighted Overlay tool with AHP derived weights to create the accumulated cost surface. Formatting each sub-criteria relationship (represented in Table 8) as individual cost surfaces is completed by the following pre-processing workflow, which includes the feature class output names in the FGDB in parentheses (saved as “...”):

1. Import all the data in Table 8's "File Name" column to the FGDB and projecting them into the project's coordinate reference system.
2. Merging "Road Type at Crossing" feature classes and "Infrastructure" feature classes together, respectively, using *Data Management: Merge* (saved as "All_Roads" and "All_Infrastructure," respectively).
3. Using the *Data Management: Mosaic to New Raster* tool, mosaic the nine digital elevation model TIFF rasters from the "Slope" sub-criterion to create one continuous surface (saved as "MosaicDEM").
4. Draw .25-, .50-, .75-, and 1-mile buffers around the "All_Infrastructure" feature class using the *Analysis: Multiple Ring Buffer* tool (saved as "Infrastructure_Buff").
5. Clip all sub-criteria to the project's study area feature class and add "_clip" as an extension to the outputted files names (saved as "Infrastructure_Buff_clip," "NPS_clip," "All_Roads_clip," "NLCD_clip," and "MosaicDEM_clip," respectively).
6. Separately convert the "Infrastructure_Buff_clip" feature class and the clipped feature class for the sub-criterion "National Park Existence" ("NPS_clip") to raster format using the *Conversion: Polygon to Raster* tool. Ensure the processing extent is set to the study area feature class in the environment settings of the *Conversion* tool (saved as "Inf_Buff_raster" and "NPS_raster," respectively).
7. Convert the "All_Roads_clip" polyline feature class to raster using the *Conversion: Polyline to Raster* tool. Ensure the processing extent is set to the study area feature class in the environment settings of the *Conversion* tool (saved as "Roads_raster").

8. Using *Spatial Analyst*: Reclassify tool, individually reclassify the raster cells in the “CostSurface_LandCover,” “CostSurface_NationalParks,” “CostSurface_Roads,” “CostSurface_Infrastructure,” and “CostSurface_Slopes” raster surfaces to a 1-5 (low cost – high cost) range of values. Each raster surface is reclassified based on the corresponding tables below, which also include the number of cells that result in each classification.

Afterwards, the cost surfaces are prepared to be combined to create an accumulated cost surface.

The reclassification of the individual raster layers is presented in Figures 9-13.

Table 9 – Reclassification values for “CostSurface_LandCover” feature class.

<u>NLCD Land Cover/Use</u>		<u>Reclassify Results</u>	
Cost Value	Classification	Cell Count	Percentage
5	Open Water	1092	0.0047%
4	Hay/Pasture & Cultivate Crops	19982	0.0862%
3	Developed (Low, Med, High)	112958	0.4875%
2	Deciduous/Evergreen/Mixed Forest & Woody/Emergent Herbaceous Wetlands	95508	0.4122%
1	Developed (Open), Barren Land, Shrub/Scrub, & Herbaceous	22941086	99.0093%

Table 10 - Reclassification values for “CostSurface_Infrastructure” feature class.

<u>Infrastructure Proximity</u>		<u>Reclassify Results</u>	
Cost Value	Buffer Distance	Cell Count	Percentage
5	cell <=0.25m	10435	0.0450%
4	0.25m < cell <=0.50m	29069	0.1255%
3	0.50m < cell <= 0.75m	45778	0.1976%
2	0.75m < cell <= 1m	60551	0.2613%
1	cell > 1m	23024793	99.3706%

Table 11 - Reclassification values for "CostSurface_Slopes" feature class.

<u>Percent-Rise Slope</u>		<u>Reclassify Results</u>	
Cost Value	% Range	Cell Count	Percentage
5	35% < cell <= 100%	25719	0.1110%
4	10% < cell <= 35%	510264	2.2022%
3	4% < cell <= 10%	766975	3.3101%
2	2% < cell <= 4%	3674462	15.8583%
1	cell <= 2%	18193206	78.5184%

Table 12 - Reclassification values for "CostSurface_Roads" feature class.

<u>Road Type (For Grade Crossings)</u>		<u>Reclassify Results</u>	
Cost Value	RTTYP (DoT) Code	Cell Count	Percentage
5	Interstate (I) & US Route (U)	31274	0.1350%
4	State (S) & County (C)	8938	0.0386%
3	Common (M)	230060	0.9929%
2	Other (O) & Unknown ()	362491	1.5644%
1	No Roads Present	22537863	97.2691%

Table 13 - Reclassification values for "CostSurface_NationalParks" feature class.

<u>National Parks</u>		<u>Reclassify Results</u>	
Cost Value	Classification	Cell Count	Percentage
5	National Park Exists	5323318	22.9744%
1	No National Park Present	17847308	77.0256%

b.) System Facilitated Accessibility Data

It is important to mention how this group of data is created because of their functionality in this analysis and how some may represent data that is unavailable to the knowledge of this paper's author. Furthermore, it is equally important to expose the difference between the polyline feature classes that represent the existing (as of the year 2020) railway network in LA County

and the pseudo-Virgin Train HSR feature class. In this study's System Facilitated Accessibility Analysis (SFAA), the LCP created and proposed in the LCPA analysis will be utilized in the network dataset when measuring the future state of system facilitated accessibility. Thus, when the terms "Railways", railway network, or network dataset are mentioned in the context of this analysis' network dataset or system facilitated accessibility study, one can assume that the LCP feature class is included in that discussion. Through the *Data Management: Merge* tool, this feature class is combined with the rest of the existing railway feature classes resulting in one feature class consisting of the entire "Railways" network polyline features. This does not include "Transfer Stations" or "Transfer Streets," "Stations," or "Station Entrances," as they are each standalone feature classes within the same FGDB (Table 14). In other words, SFAA comes after the LCPA due to its reliance on the LCP created in LCPA (see geospatial workflow in Figure 7 below), however, the data collection and formatting for this objective is discussed first here.

The U.S. Census Bureau's TIGER/Line road shapefiles are utilized in the system facilitated accessibility objective of this study and serve as one of six inputs in creating the network dataset. Other inputs and brief definitions of those inputs are presented in Table 14. "Roadways" is LA, San Bernardino, and Clark County's TIGER/Line feature classes merged with *Data Management: Merge*. The existing "Railways" network is represented by four railways (Figure 2) which include the LCP alternative HSR corridor developed in this study during LCPA, and the Metro, Metrolink, and Amtrak railways which can facilitate access to Victorville where it's possible to connect to the new VTUSA HSR.

Table 14 – Network dataset elements, how they were derived and their function.

<u>Name</u>	<u>Function</u>	<u>Source</u>
Roadways	Facilitates travel by car	U.S. Census Bureau
Railways	Facilitates travel by railway	Created from points to line tool in QGIS
Stations	Stops along railways that facilitate access between railways to roads	Geocoded station addresses from Google
Station Entrances	Stops along roadways that facilitate access from roads to railways	Computed via the <i>Analysis: Near</i> tool. Are XY events snapped to the nearest road edge
Transfer Streets	Vector edges that simulate the distance between station entrances and stations	Digitized vector edges between “near” station entrances and geocoded stations
Transfer Stations	Vector edges that simulate railways that are interconnected by their corresponding stations	Digitized vector edges between stations that facilitate moving between lines at limited locations

The “Railways” “Stations” coordinates were derived in ArcMap from performing address geocoding on field tables containing each station’s address listed on www.Google.com. The point features contain fields for the corresponding coordinates and their respective address after the geocoding process. These points are saved into the study’s FGDB and are exported from ArcMap as shapefiles. They are also exported as shapefiles, rather than only placed into the FGDB, because each individual railway’s shapefile of stops along the rail line act as inputs for the QGIS software application tool: “Points to Line.” The FOSS application QGIS was employed at this stage of the data formatting process due to its simplified workflow creating lines from points. The lines generated in QGIS are exported as shapefiles and stored as feature classes along with the copy of station point feature classes back in ArcMap.

“Station Entrances” is a point feature class created with the *Analysis: Near* tool. “Station Entrances” are represented as points nearest the “Stations” feature class on the “Roadways” feature class. The *Analysis: Near* tool is implemented on the “Stations” feature class. Using *Analysis: Near* serves the purpose of creating “Station Entrances.” *Analysis: Near* takes an

inputted feature class and calculates the coordinates of the nearest feature and the distance to that feature of another inputted near feature class. In this case, the near feature class is the “Roadways” network and running *Analysis: Near* to calculate points on the “Roadways” feature class nearest the station feature class creates two new fields holding the coordinates of each point per station feature. After making a temporary “XY Event Layer” from these new coordinate fields (“NEAR_X” “NEAR_Y”), the layer can be saved as its own feature class, ultimately creating a new set of points with their own representations near the stations. These “Near” points are the acting “Station Entrance” points from the “Roadways” to the “Station” points and the “Railways” network. For connectivity reasons underlying network dataset creation, it is crucial that the “Station Entrances” lie on the road network as the stations themselves fall on the “Railways” network.

Within the network dataset, “Transfer Streets” and “Transfer Stations” serve the same purpose of each other, but between two different groups of points (Figure 6). Each of these polyline feature classes act as a transfer corridor. As ArcMap solves a route between a network dataset’s user-inputted origin and destination, (called “Stops” in ArcMap) it will need a way to move from the “Station Entrance” point to a “Station” point, or vice versa, in order to access the next polyline (e.g. “Roadways” or “Railways”). Likewise, when ArcMap is solving a route and wants to switch “Railway” polylines via the “Stations” that realistically allow them to do so, it will need a vector to move from one “Station” point to another “Station” point. “Transfer Streets” and “Transfer Stations” were first created as empty shapefiles and imported into the project’s FGDB. Following an edit session and manually snapping polylines between their respective points (“Stations” to “Stations” and “Stations” to “Stations Entrances”) where

appropriate, the “Transfer Streets” and “Transfer Stations” vectors can be used in network dataset creation.

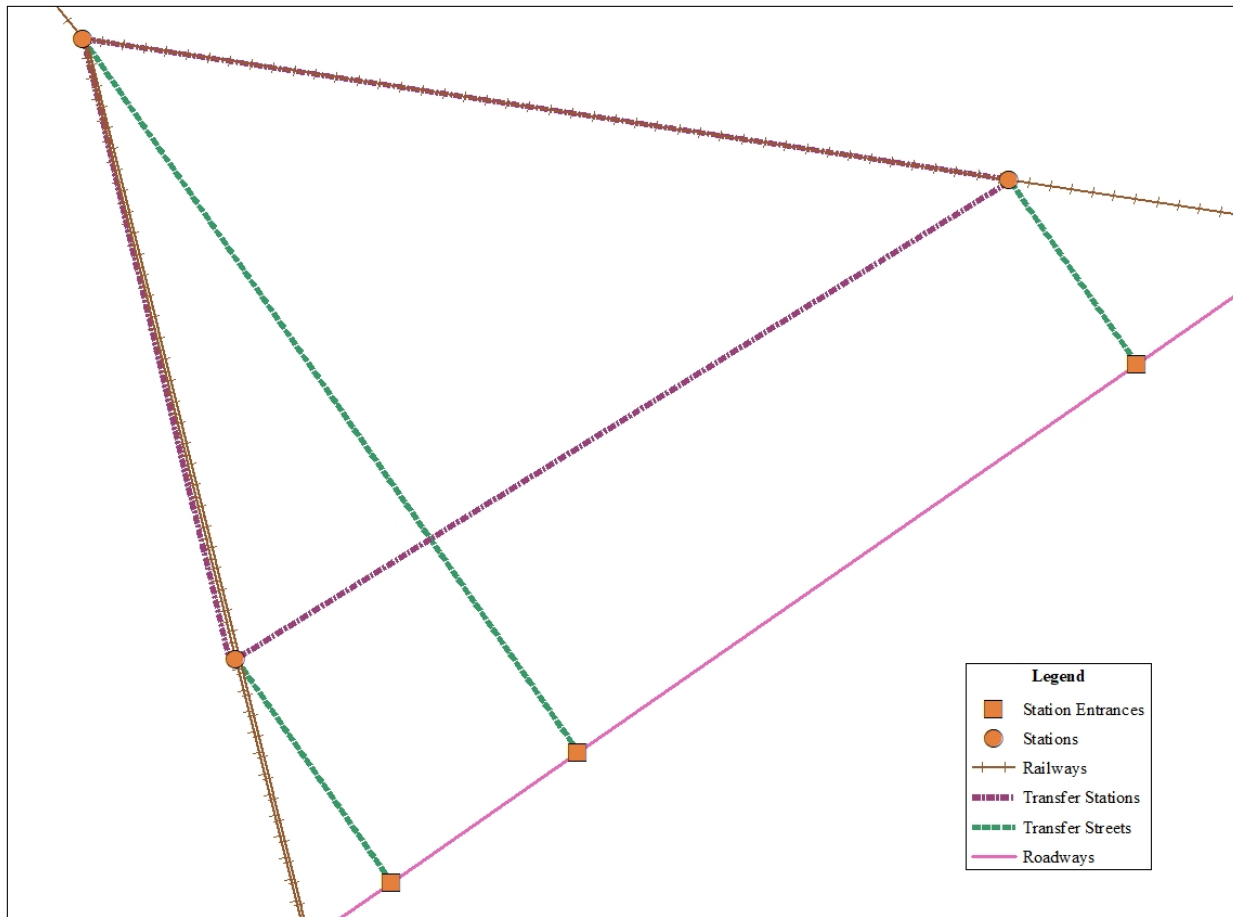


Figure 6 – “Station Entrances” on “Roadways” connect to Glendale Station Junction of Antelope Valley, Amtrak, and Ventura County Railways via “Transfer Streets.” “Stations” are interconnected by “Transfer Stations” simulating the ability to switch among the three “Railways.”

“Roadways” and “Railways” require certain unique fields to accumulate cost impedances when ArcMap is traversing the network dataset. Without at least one method of measuring impedances, the network dataset is unable to solve a route between two stops. Methods of measurements in ArcMap network datasets could consist of minutes, hours, feet, miles, or even monetary costs or other customized impedances. In order to complete Equations 8 & 9, the

“Railways” and “Roadways” features of this study’s network dataset contain multiple fields for calculating cost impedances (Table 10). The “Fare” field for any and all “Railways” is set at the fixed cost for that railway discussed in section 2.c. The “Domestic Price” field is the price of gasoline per line segment that a domestic car would spend on average travelling on that line segment, also discussed above in section 2.c. The “Miles” field is calculated from the “Feet” field which already exists for every feature. Given the project’s coordinate reference system, the linear units are set to feet, so all that remains is to divide each feature by 5,280 to receive the number of miles per line segment. The “Hours” and “Minutes” fields are supported by a separate field “Speed.” The “Speed” field is the maximum speed limit legally allowed to be reached by the entity traveling in the network. To calculate the “Hours” spent on each line segment throughout the network dataset, one takes the total length in miles of that line segment and divides by the “Speed” field. To calculate the “Minutes” field, one simply would multiply the hours by 60. Each route that is solved in the network dataset will contain new fields that total each of these cost impedance fields, respectively (e.g., “Total_Minutes”, “Total_Domestic_Price”, etc.).

Table 15 – Attributes of the network dataset.

<u>Name</u>	<u>Usage</u>	<u>Units</u>	<u>Railways Field Name</u>	<u>Roadways Field Name</u>	<u>Equation</u>
Fare	Cost	Monetary	"Cost"	N/A	<i>*Fixed Price*</i>
Domestic Price	Cost	Monetary	N/A	"Domestic_Price"	"Shape_Length_Miles" * \$3.45
Feet	Cost	Feet	"Shape_Length"	"Shape_Length"	<i>*Shape_Length already in Feet units*</i>
Miles	Cost	Miles	"Length_Miles"	"Shape_Length_Miles"	"Shape_Length" / 5280
Hours	Cost	Hours	"Hours"	"Hours"	"Length_Miles" or "Shape_Length_Miles" / "Speed"
Minutes	Cost	Minutes	"Minutes"	"Minutes"	"Hours" * 60

There exists one final group of data that is not mentioned in Table 9 because it is not crucial to the construction of the network dataset. These are the origin and destination points, or “Stops” that are inputted into the network dataset. The “Stops” are created from calculated census tract and county centroids in ArcMap. The census tract polygon shapefile downloaded from the U.S. Census Bureau for LA County is given a unique identifier field named “ID,” ranging from 1-2,345, as well as two new fields named “X_Cord” and “Y_Cord.” These new “X_Cord” and “Y_Cord” fields are calculated using ArcMap’s geometry calculator, based on the feature classes coordinate reference system, and are filled with the X & Y coordinates of the center of each the feature. Like the “XY Event Layer” used in creating the geocoded railway stations, these centroid coordinates are saved as their own feature class representing the origin “Stops.” This same process is done to the centroid of Clark County, NV polygon, which acts as the destination “Stop,” and happens to fall inside Las Vegas. Similar to the necessity of “Stations” and “Station Entrances” lying on the railways and roadways, for connectivity reasons, the “Stops” need to lie on a network dataset “Roadways” polyline feature class as well. Both these groups of points are then snapped to the nearest roadway feature in the “Roadways” feature class using *Analysis: Near* tool and are saved as their own feature class.

Serving this analysis as the origin/destinations for the “Stops” in the network dataset, each origin/destination pair is inputted into a Python script created to merge each census tract centroid to the centroid of Clark County in Las Vegas. Beforehand, each census tract is divided according to their centroids into individual feature classes and merged with the Clark County destination centroid. To divide the census tract centroids, the *Analysis: Split by Attribute* tool is run on the “ID” field of the census tract centroids, and 2,345 separate files were created and stored in a scratch workspace. Following splitting the origins by attributes, a Python script is

created to use ArcMap's *Data Management: Merge* tool. The batch-script merged each census tract centroid to the Clark County centroid and called the new output a unique name ("Stop_0001", "Stop_0002, etc.) stored in their own separate FGDB. The "ID" field in each new stop feature class contains the corresponding "ID" field for each census tract it originates from. This is useful later in the analysis when combining the system facilitated accessibility measurement with the original census tract feature class.

4.) Software & Hardware

The primary software utilized in this analysis is Esri's ArcGIS for Desktop (v.10.8) (also known as ArcMap). Although, ArcMap 10.8 still operates *Network Analysis* under ArcMap v.10.1. QGIS (formerly, Quantum-GIS), was created by the Open Source Geospatial Foundation's (OSGeo) as a free-and-open-source (FOSS) GIS software application. QGIS is operated under the GNU's Not Unix! (GNU) General Public License. OSGeo's QGIS (v.3.12.2) mapping software is used for a small portion of pre-processing data, but most pre-processing and all geospatial analysis is done using ArcMap. While QGIS is a FOSS software component of the project, ArcMap, a proprietary software application, is provided to the author under a "Desktop Advanced Single-Use License" for participating in the GIS graduate program through Penn State University. PyCharm is an integrated development environment (IDE) software application for writing Python code. Developed by JetBrains in late 2010, PyCharm is cross platform and can be used on Windows, Mac, and Linux operating systems. PyCharm's Community Edition (v.11.0.7) is the chosen IDE for working with the ArcPy application programming interface (API) during this analysis because of its FOSS nature, specialized project views, and file structure. PyCharm Community Edition operates under the Apache 2 License, a lenient free software license written by the Apache Software Foundation (ASF).

Below is a list of hardware components utilized for this study as it relates to the ArcGIS v.10.8 Hardware Requirements help page by Esri (2020). All hardware used in this study is operated on Microsoft's Windows 10 operating system (OS). Five of the six listed components below meet the recommended and supported hardware requirements and all hardware components were purchased and assembled by the author. The computer hardware components utilized for this study as it relates to ArcMap v.10.8 requirements are:

- Inter® Core™ i7-4770K CPU at 3.5GHz
- 64-bit OS, x64-based processor
- 16GB of Memory/Ram
- Two 1920x1080 Screen Resolution at 8-bit color depth (recommended 24-bit).
- 1TB Samsung SSD 860 EVO Disk Drive
- NVIDIA GeForce GTX 770 Graphics Card

5.) Analysis

The full analytical geospatial workflow begins with data collection and formatting, followed by a series of LCPA and SFAA geospatial tasks, and ending with an evaluation of the results for each objective. Recall from section 1 that these objectives are to a.) propose an alternative least-cost path for the construction of a high-speed electric railway (HSR) project connecting two locations – Victorville and Las Vegas, and b.) visualize the current and future state of LA County's system facilitated accessibility to Las Vegas with the anticipated VTUSA HSR. Before the network dataset is built for SFAA, the LCP is proposed during LCPA. Again,

this is because the LCP is required for SFAA. The following paragraphs outlining the analytical steps taken to achieve suitable results for this study are completed using the software and technology outlined in section 4.

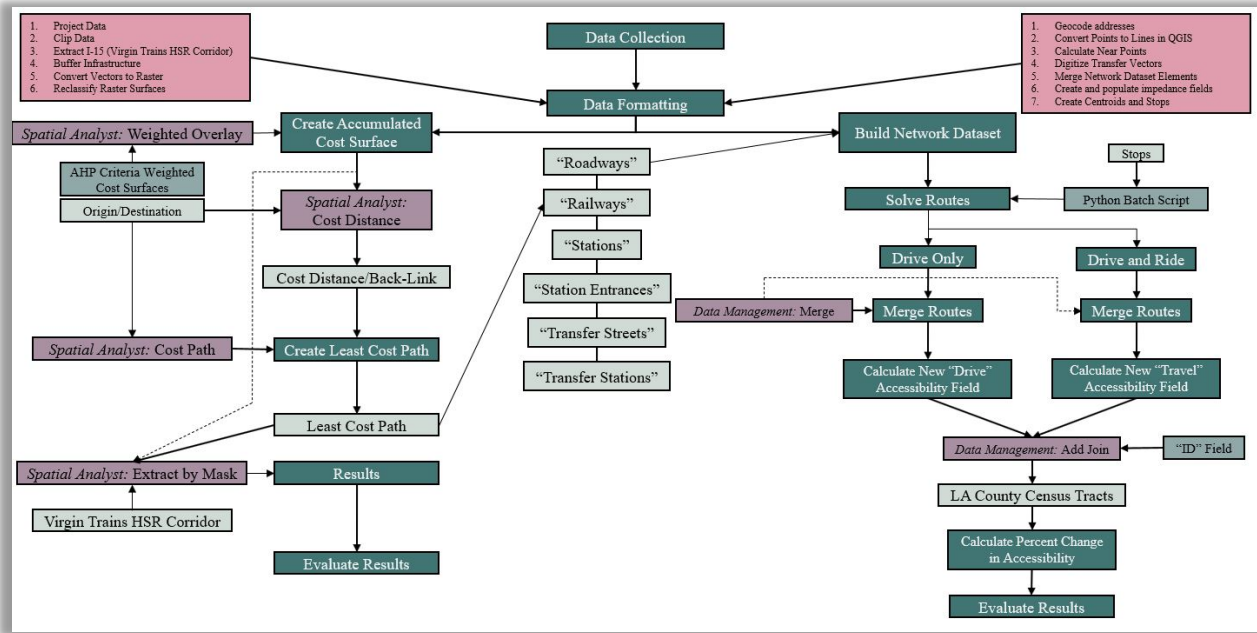


Figure 7 -Full geospatial workflow for Least-Cost Path Analysis (LCPA) and System Facilitated Accessibility Analysis (SFAA).

a.) Least-Cost Path Analysis

To create the LCP, the *Spatial Analyst: Cost Path* tool is utilized. *Spatial Analyst: Cost Path* requires three inputs: a destination cell, and cost distance and cost back-link raster surfaces. As briefly explained in the beginning of section 3, the vector feature classes representing VTUSA’s proposed Victorville and Las Vegas stops will act as the origin and destination cells, after they are converted to raster format with the *Conversion: Points to Raster* tool. The cost distance and cost back-link surfaces are created simultaneously using origin and destination cells and the *Spatial Analyst: Weighted Overlay* tool’s output.

To create the accumulated cost surface generated by the *Spatial Analyst: Weighted Overlay* tool, the five individual cost surfaces representing each sub-criterion relationship are required. Earlier, during data formatting for LCPA, the five cost surfaces were generated using a series of pre-processing steps and the *Spatial Analyst: Reclassify* tool (for results, see Tables 9-13). The *Spatial Analyst: Weighted Overlay* tool's user interface is displayed in Figure 8.

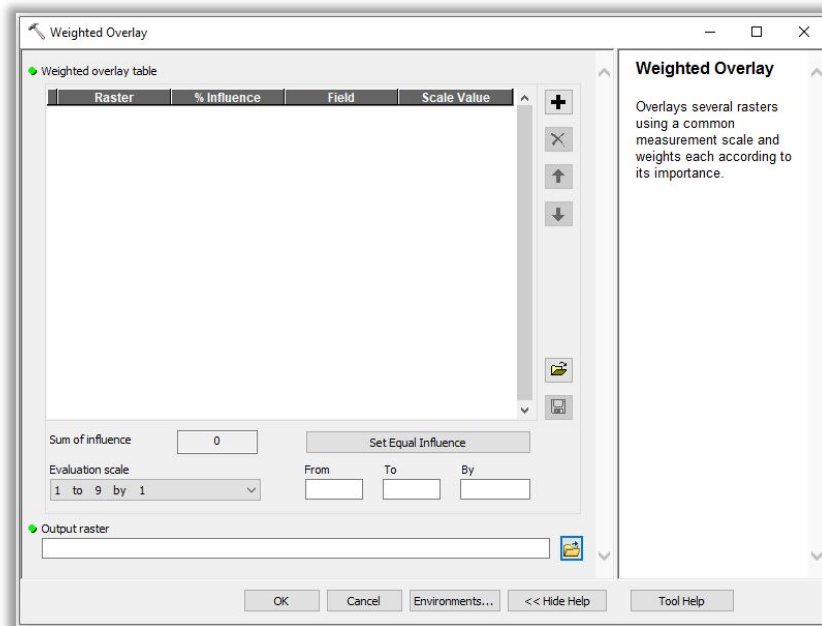


Figure 8 – *Weighted Overlay* can be located in the ArcToolbox: “*Spatial Analyst: Overlay*.”

The five cost surfaces are inputted *Spatial Analyst: Weighted Overlay* tool and given percent influences based upon their AHP calculated criteria weights. Discussed above in section 2.a., these weights are produced via multiple pairwise comparison matrices (PCMs), each favoring a particular criterion, and then averaged together to create a best-attempt at a realistic PCM that would have normally been determined by experts/stakeholders for a HSR-LCP construction. It is important to remember that these PCMs follow the same AHP procedure outlined in section 2.a. during the mock example and are judged by their consistency ratio (CR). Each of the five PCMs

for the 5 sub-criteria and their CRs are displayed in Tables 16-20. The final, average PCM, criteria weights, and CR are displayed in Table 21.

Table 16 - Pairwise comparison ranking the importance of National Park Lands being used for HSR construction.

Pairwise Comparison Matrix - "CostSurface NationalParks"					
	National Parks	Slope	Road Type	Land Use	Infrastructure Proximity
National Parks	1.000	2.000	3.000	2.000	2.000
Slope	0.500	1.000	2.000	1.000	1.000
Road Type	0.333	0.500	1.000	0.500	0.500
Land Use	0.500	1.000	2.000	1.000	1.000
Infrastructure Proximity	0.500	1.000	2.000	1.000	1.000
Sum	2.833	5.500	10.000	5.500	5.500
Number of Criteria	5	CR	0.194	CR Rounded	0.19

Table 17 - Pairwise comparison ranking the importance of high slope areas being used for HSR construction.

Pairwise Comparison Matrix - "CostSurface Slope"					
	Slope	National Parks	Road Type	Land Use	Infrastructure Proximity
Slope	1.000	2.000	3.000	3.000	2.000
National Parks	0.500	1.000	2.000	2.000	1.000
Road Type	0.333	0.500	1.000	1.000	0.500
Land Use	0.333	0.500	1.000	1.000	0.500
Infrastructure Proximity	0.500	1.000	2.000	2.000	1.000
Sum	2.667	5.000	9.000	9.000	5.000
Number of Criteria	5	CR	0.253	CR Rounded	0.25

Table 18 - Pairwise comparison ranking the importance major and minor roads being used for HSR-crossing construction.

Pairwise Comparison Matrix - "CostSurface Roads"					
	Road Type	National Parks	Slope	Land Use	Infrastructure Proximity
Road Type	1.000	2.000	2.000	3.000	3.000
National Parks	0.500	1.000	1.000	2.000	2.000
Slope	0.500	1.000	1.000	2.000	1.000
Land Use	0.333	0.500	0.500	1.000	1.000
Infrastructure Proximity	0.333	0.500	1.000	1.000	1.000
Sum	2.667	5.000	5.500	9.000	8.000
Number of Criteria	5	CR	0.231	CR Rounded	0.23

Table 19 - Pairwise comparison ranking the importance of NLCD land classifications being used for HSR construction.

Pairwise Comparison Matrix - "CostSurface LandCover"					
	Land Use	National Parks	Slope	Road Type	Infrastructure Proximity
Land Use	1.000	2.000	2.000	3.000	3.000
National Parks	0.500	1.000	1.000	2.000	2.000
Slope	0.500	1.000	1.000	2.000	2.000
Road Type	0.333	0.500	0.500	1.000	1.000
Infrastructure Proximity	0.333	0.500	0.500	1.000	1.000
Sum	2.667	5.000	5.000	9.000	9.000
Number of Criteria	5	CR	0.253	CR Rounded	0.25

Table 20 - Pairwise comparison ranking the importance of lands in close proximity to critical infrastructure being used for HSR construction.

Pairwise Comparison Matrix - "CostSurface Infrastructure"					
	Infrastructure Proximity	National Parks	Slope	Road Type	Land Use
Infrastructure Proximity	1.000	3.000	2.000	3.000	2.000
National Parks	0.333	1.000	0.500	1.000	0.500
Slope	0.500	2.000	1.000	2.000	1.000
Road Type	0.333	1.000	0.500	1.000	0.500
Land Use	0.500	2.000	1.000	2.000	1.000
Sum	2.667	9.000	5.000	9.000	5.000
Number of Criteria	5	CR	0.253	CR Rounded	0.25

Table 21 – The averaged pairwise comparison ratings based upon Tables 16-20. Criteria Weights determined in this AHP equation are entered into the Spatial Analyst: Weighted Overlay tool.

Pairwise Comparison Matrix - Averaged Cost Surfaces						
	Infrastructure Proximity	National Parks	Slope	Road Type	Land Use	Criteria Weights
Infrastructure Proximity	1.000	1.100	1.000	1.667	1.267	0.1991
National Parks	1.467	1.000	1.000	1.700	1.400	0.2159
Slope	1.300	1.300	1.000	1.900	1.500	0.2298
Road Type	1.067	0.867	0.767	1.000	1.067	0.1595
Land Use	1.200	1.100	0.967	1.667	1.000	0.1957
Sum	6.033	5.367	4.733	7.933	6.233	
Number of Criteria	5	CR	0.237	CR Rounded	0.24	

Post handling the proof-in-concept AHP model, the criteria weights displayed in Table 21 are rounded and entered into the *Spatial Analyst: Weighted Overlay* tool. The processing extent is set to the study area boundary feature class for LCPA, and the remaining environment settings

are set to default. The output raster represents the analysis' accumulated cost surface and is saved into the FGDB as "AccCostSurface_CR24" (Figure 9).

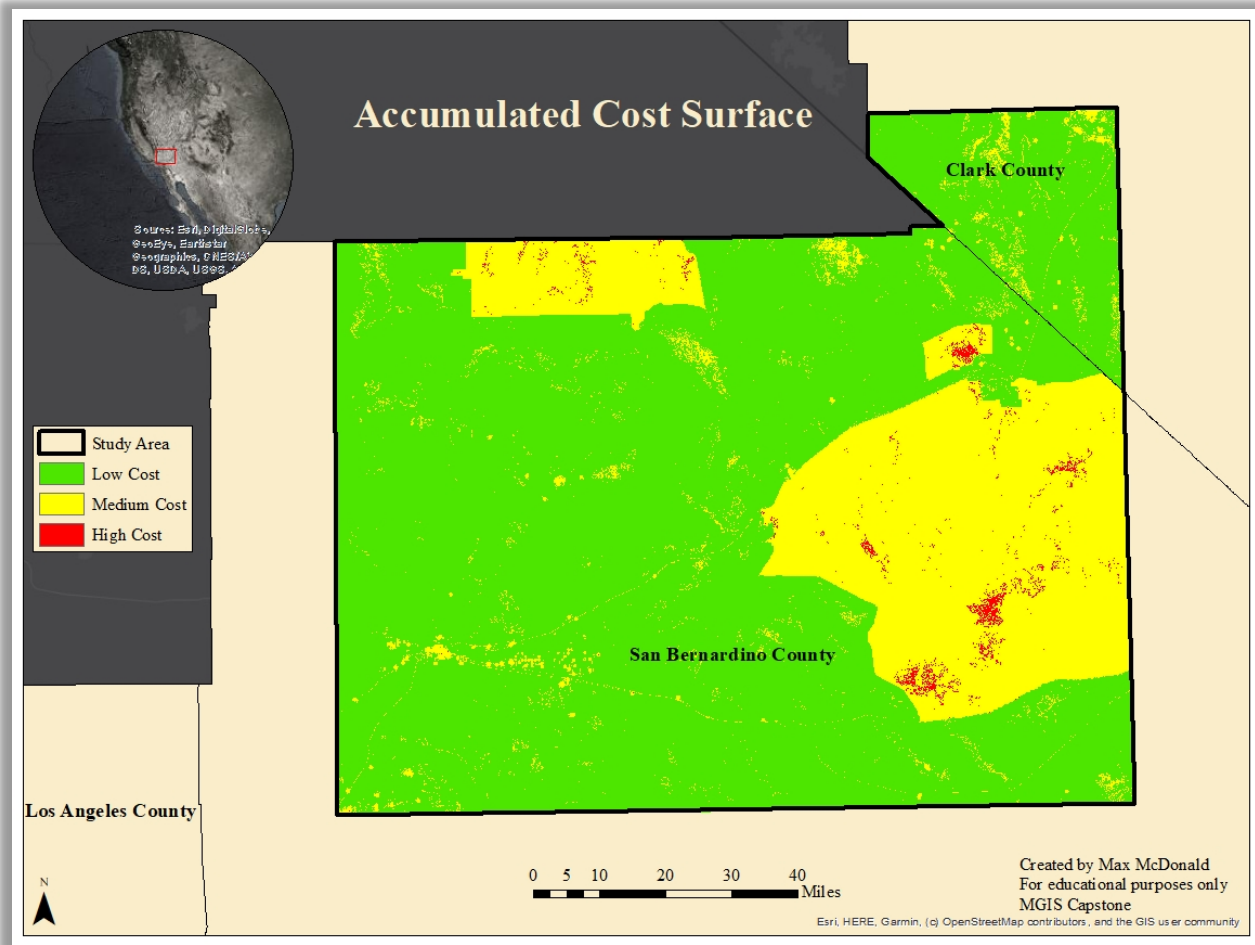


Figure 9 – The accumulated cost surface landscape for LCP creation.

Cost Distance and Cost Back Link surfaces are created simultaneously using the *Spatial Analyst: Cost Distance* tool (Figure 10). The outputs are saved as "AccCostDistance_CR24" and "AccCostBackLink_CR24," respectively. Cost Distance surfaces (Figure 11) are built using the accumulated cost surface and the origin cell and calculate the least accumulative distance from each cell to the origin in the study area's extent. Cost back-link surfaces (Figure 12) are created

with the same accumulated cost surface and origin cell and calculate each cell's best-neighboring cell, which is in the direction of the least accumulative path to the origin cell, within the study area's extent.

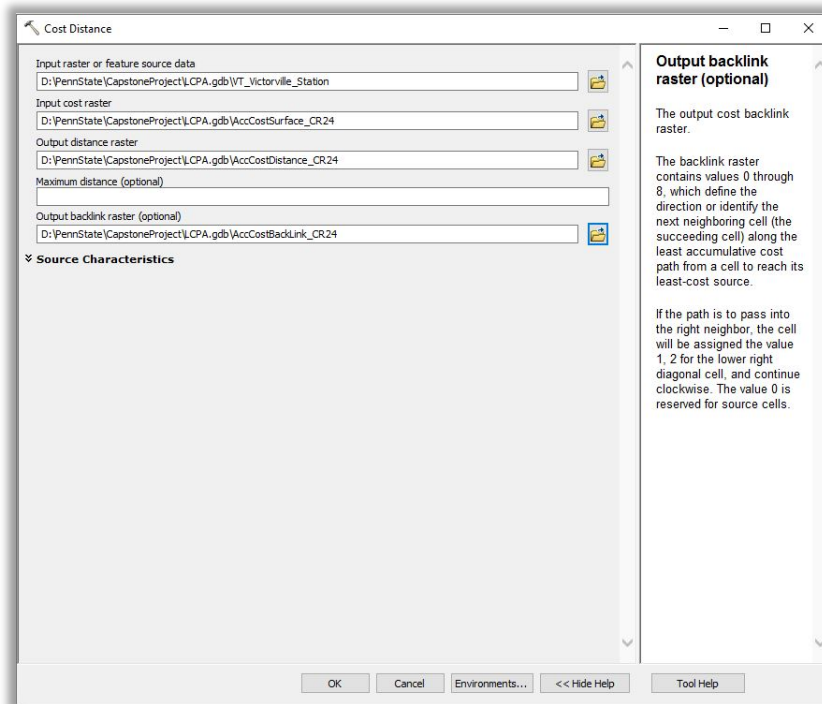


Figure 10 – Cost Distance can be located in the ArcToolbox: “Spatial Analyst: Distance.”

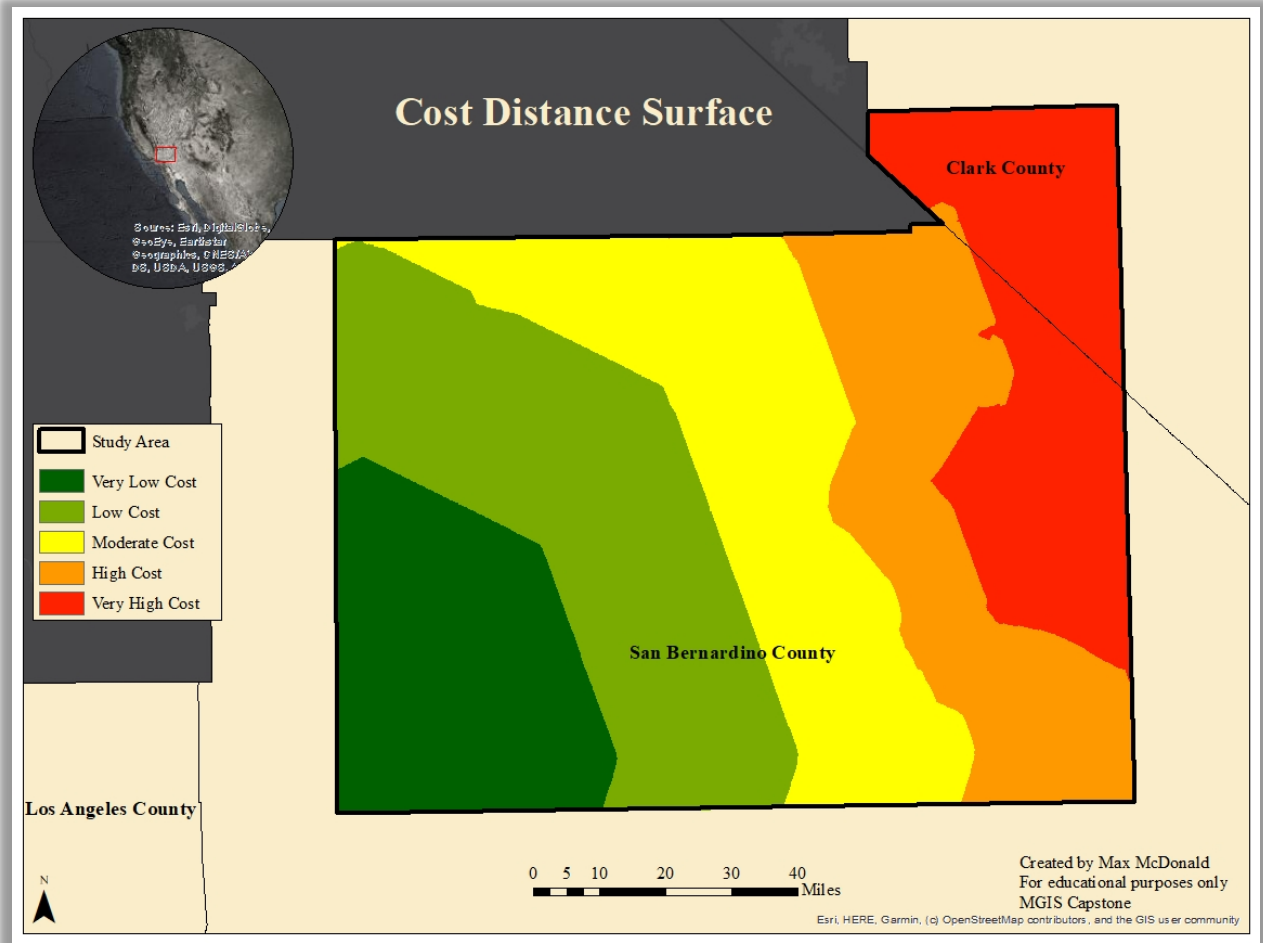


Figure 11 – Cost Distance raster surface used in this analysis.

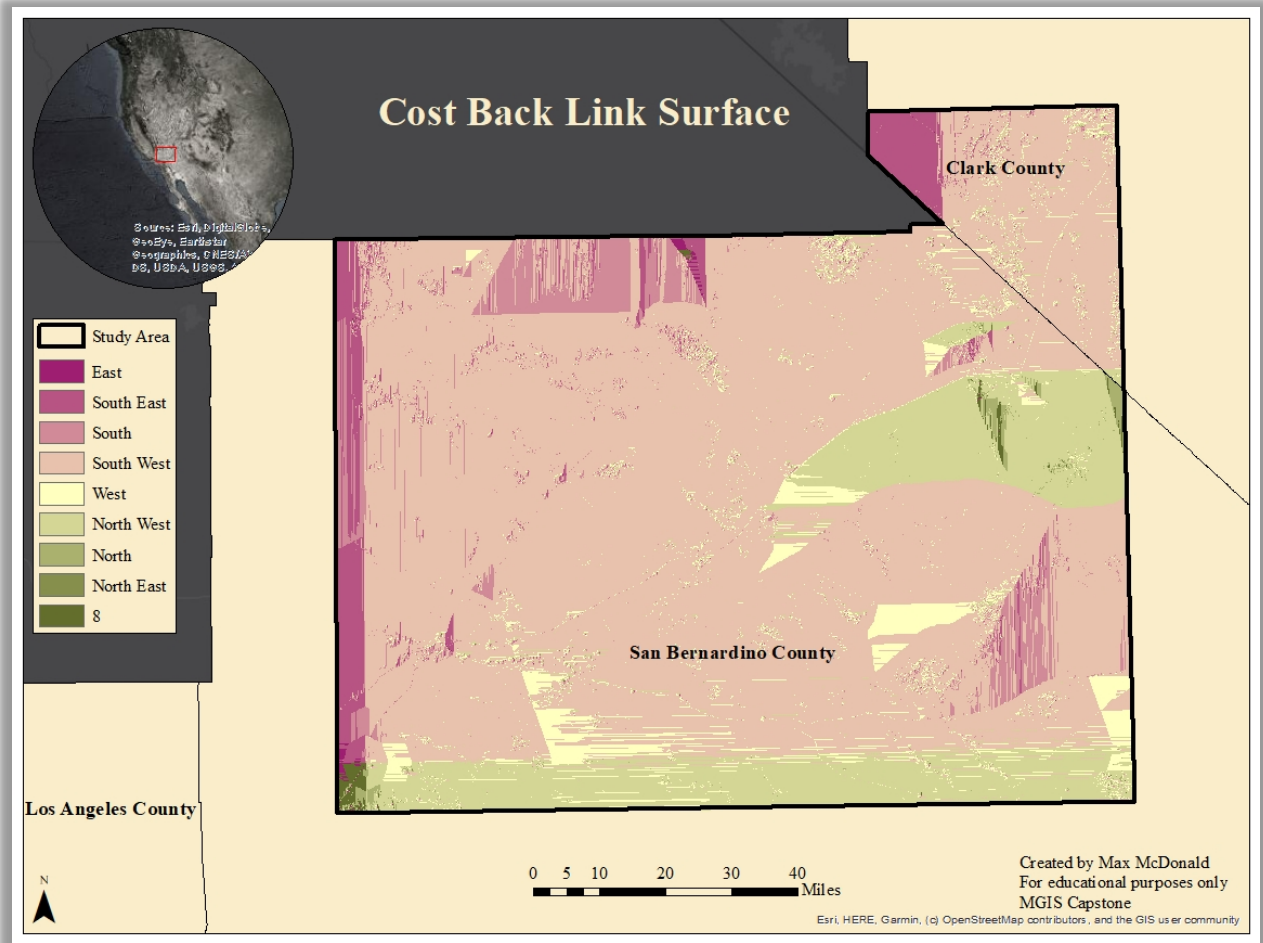


Figure 12 – Cost Back Link raster surface used in this analysis.

At this point in the analysis the three required inputs for *Spatial Analyst: Cost Path* are prepared and can be entered accordingly. Figure 13 displays the inputs for this study’s iteration of *Spatial Analyst: Cost Path*.

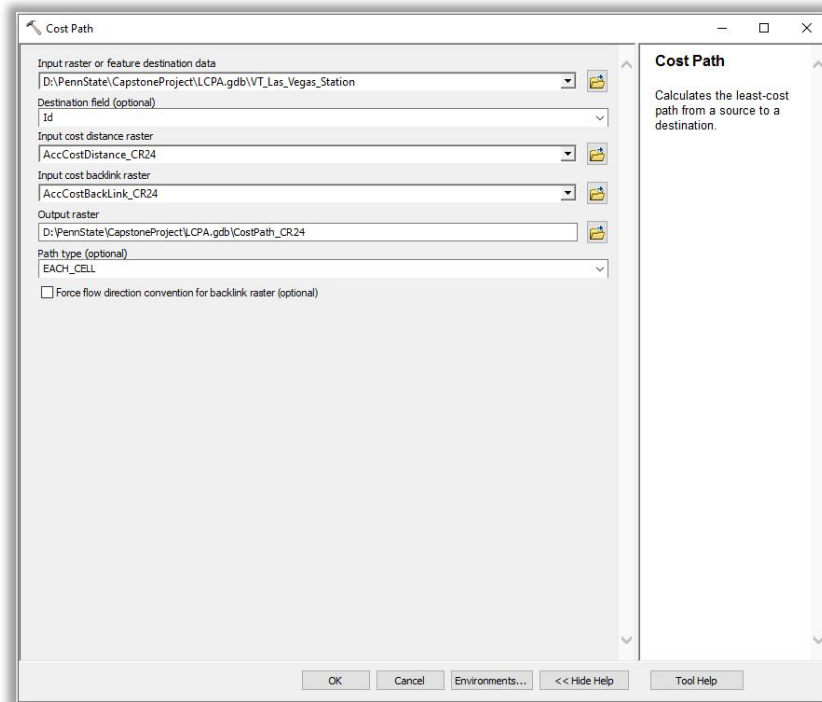


Figure 13 - Cost Path can be located in the ArcToolbox: "Spatial Analyst: Distance."

Spatial Analyst: Cost Path is knowledgeable of the source cell based upon the inputted cost distance and cost back link surfaces. If a path can be found and completed between the source and destination, the output will generate a new raster surface feature class (saved as "CostPath_CR24") showing the cells upon the LCP ArcMap would travel between the two points. One can convert this raster surface with the *Conversion: Raster to Polyline* tool for a better visualization of said LCP. The result of this study's LCP construction is visually contrasted with the VTUSA's proposed HSR corridor and displayed in Figure 14.

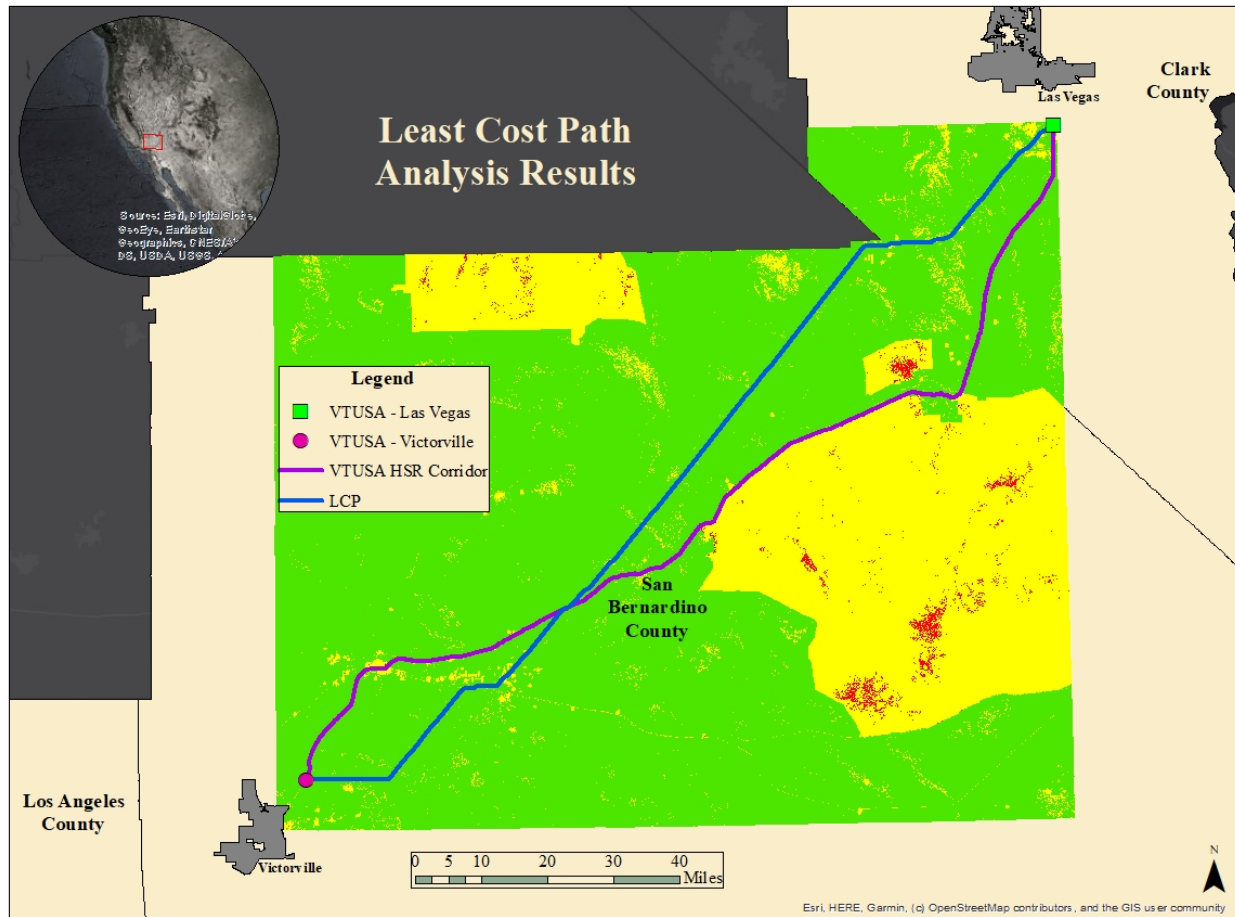


Figure 14 – The LCP contrasted against the proposed HSR corridor by VTUSA.

As mentioned earlier, it is not enough to compare corridors side-by-side on a map. One must have a quantifiable way for evaluating them. One can extract and measure the efficiency of both routes displayed in Figure 14 using the *Spatial Analyst: Extract by Mask* tool. This tool extracts the cells within the chosen raster that correlate with the vector feature class. In order to view and analyze the results of this study's LCPA, the *Spatial Analyst: Extract by Mask* tool is performed on the cost surface using the two corridor polyline feature classes in Figure 14 (discussed further in section 6). Afterwards one can evaluate the total length of each path and how many cost cell categories through which it traverses.

b.) System Facilitated Accessibility Analysis

Once the network dataset is constructed using all six feature class elements presented in Table 9 above, one can begin to input “Stops” to the network dataset to be solved one-by-one. In this study, it is inefficient to manually perform this step in the SFAA due to the sheer number of routes that are required to be calculated. Recall that there are 2,346 census tract polygons within LA County (Figure 15).

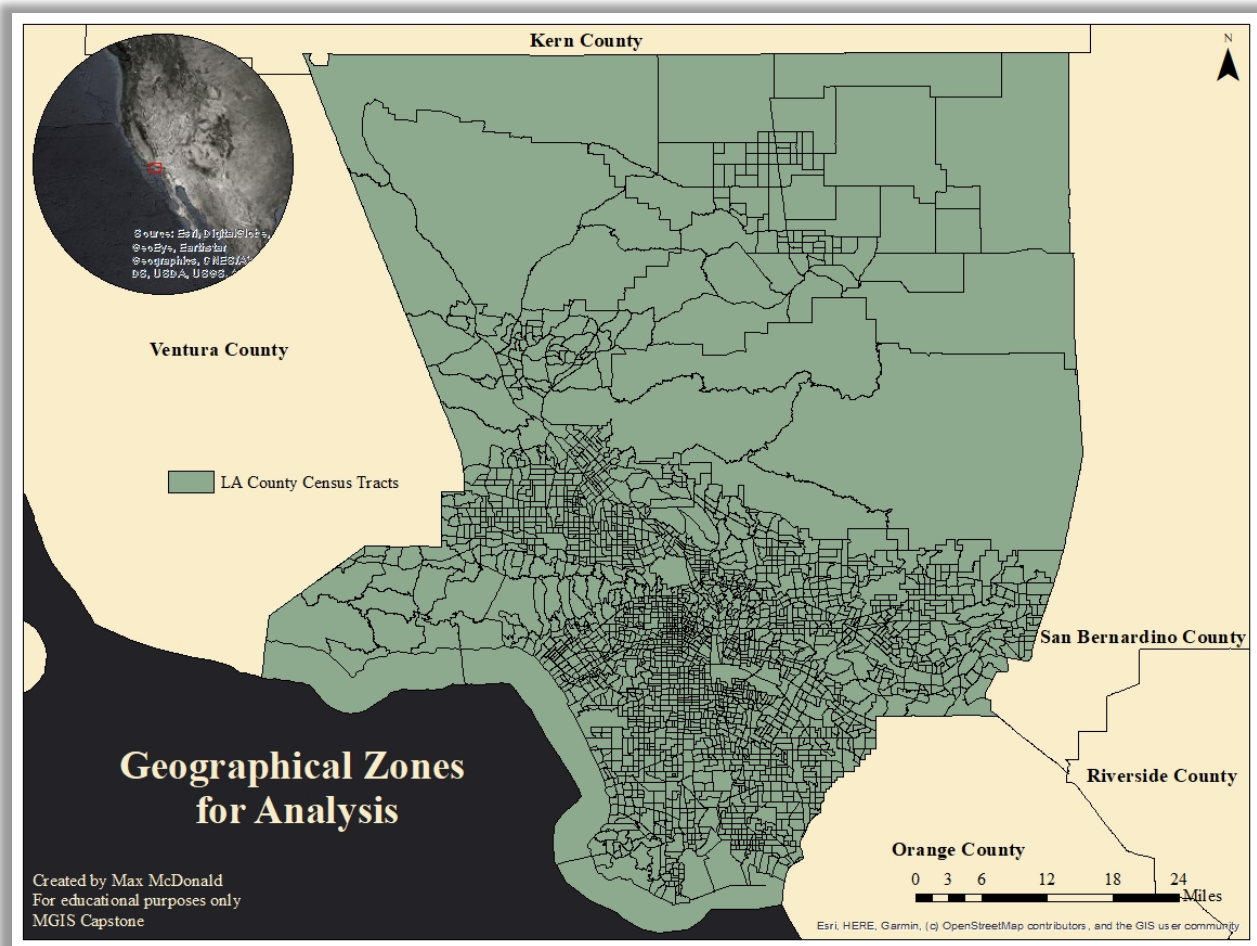


Figure 15 – Each LA County Census Tract will act as the geographical zones for measuring system facilitated accessibility. Therefore, after formatting the origin and destination (“Stops”) into pairs with their individual “ID” fields, one could automate the process of solving each route with Python and save the results

to a FGDB. In order to compare the current and future states of system facilitated accessibility, the Python automated task is completed twice. Within the network dataset parameters, a restriction attribute is created to simulate traversing through the network dataset without the option to enter a railway. This restriction (called “DriveOnly”) makes the ArcMap *Network Analyst: Solve* tool unable to consider the “Railways” elements of the network dataset. Thus, one automated SFAA script is conducted with the “DriveOnly” restriction turned on, and one with the restriction turned off.

The Python script utilized for this stage in the analysis is split up here into the environment settings and local variables (Figure 16) and the for-loop (Figure 17) used to loop through each pair of “Stops” and solve a route. This demonstrates an example of solving the routes with the “DriveOnly” restriction turned off. To turn “DriveOnly” on within the Python script, the `arcpy.MakeRouteLayer_na()` class would have to include “DriveOnly” where nothing is included in the environment setting parameters (Figure 18).

```

1  # This script inputs a pair of points into a network data set,
2  # solves for the best route, then saves the route to a location
3  # Max McDonald
4  # Created on 07-15-2020
5  # -----
6  # ArcPy tools of mention
7  # # arcpy.MakeRouteLayer_na
8  # # arcpy.AddLocations_na
9  # # arcpy.Solve_na
10 # # arcpy.SelectData_management
11 # # arcpy.CopyFeatures_management
12 # # arcpy.CheckOutExtension
13 # # arcpy.MakeFeatureLayer_management
14 # # arcpy.Delete_management
15
16
17 # import arcpy module
18 import arcpy
19
20 # Check out network analyst extension
21 arcpy.CheckOutExtension("Network")
22
23 # set environments
24 arcpy.env.workspace = r"D:/PennState/CapstoneProject/Locations.gdb"
25
26 # Local variables:
27 Network_ND = r"D:/PennState/CapstoneProject/Access.gdb/Network/Network_ND"
28 routeLYR = "RouteLayer"
29 routeLYR_2 = routeLYR
30 routeLYR_3 = routeLYR_2
31 routes = routeLYR_3
32 featureLayer = "selectedLayer"
33 counter = 1
34
35 # list feature classes in Locations gdb
36 pairList = arcpy.ListFeatureClasses()
37

```

Figure 16 – SFAA Python script pt. 1.

```

38 # Begin looping through the list for stops to enter into a network data set
39 for OD in pairList:
40     # Make Route Layer
41     arcpy.MakeRouteLayer_na(Network_ND, "RouteLayer", "T_Minutes", "USE_INPUT_ORDER", "PRESERVE_BOTH", "NO_TIMEWINDOWS",
42                             "T_Cost;T_Domestic_Price;T_Feet;T_Hours;T_Imported_Price;T_Miles;T_Minutes", "ALLOW_UTURNS", "",
43                             "NO_HIERARCHY", "", "TRUE_LINES_WITH_MEASURES", "")
44     # Add Locations
45     arcpy.AddLocations_na(routeLYR, "Stops", OD, "Name Name #", "5000 Meters", "",
46                           "ModalRoads_1 SHAPE;Railways_1 SHAPE;StationTransfer_1 SHAPE;TransferStreet_1 SHAPE;Entrances_1 "
47                           "SHAPE;Stations_1 SHAPE;Network_ND_Junctions NONE", "MATCH_TO_CLOSEST", "APPEND", "NO_SNAP",
48                           "5 Meters", "INCLUDE", "ModalRoads_1 #;Railways_1 #;StationTransfer_1 #;TransferStreet_1 #;"
49                           "Entrances_1 #;Stations_1 #;Network_ND_Junctions #")
50     # Solve the route
51     arcpy.Solve_na(routeLYR_2, "SKIP", "TERMINATE", "", "")
52     # select route Layer
53     arcpy.SelectData_management(routeLYR_3, "Routes")
54     # make it a feature layer
55     arcpy.MakeFeatureLayer_management("Routes", featureLayer)
56     # save it as a feature class
57     newRoute = r"D:/PennState/CapstoneProject/TrainAccessibility.gdb/Route_" + str(counter).zfill(4)
58     arcpy.CopyFeatures_management(featureLayer, newRoute, "", "8", "8", "8")
59     # increase counter
60     counter += 1
61     # debugger
62     print(newRoute + " saved to disk.")
63     # delete the Route Layer and feature layer
64     arcpy.Delete_management("RouteLayer")
65     arcpy.Delete_management(featureLayer)
66
67 # print completion message
68 print("Loop Completed.")

```

Figure 17 – SFAA Python script pt. 2.

```

41     arcpy.MakeRouteLayer_na(Network_ND, "RouteLayer", "T_Minutes", "USE_INPUT_ORDER", "PRESERVE_BOTH", "NO_TIMEWINDOWS",
42         "T_Cost;T_Domestic_Price;T_Feet;T_Hours;T_Imported_Price;T_Miles;T_Minutes", "ALLOW_UTURNS", "",
43         "NO_HIERARCHY", "", "TRUE_LINES_WITH_MEASURES", "")

```

Figure 18 – Insert “DriveOnly” on line 43 between the quotes holding no value to turn the restriction on during batch processing.

Each iteration (in other words, each time a route is solved) took roughly nine seconds to be completed. Therefore, each iteration of solving all the routes took roughly five hours and thirty minutes to complete on the hardware described above in section 4. During this time, three errors occurred which resulted due to centroids being snapped to isolated roads within three census tracts. These errors were accounted for by snapping the centroids of these three features to roads nearest the center, and that were connected to the majority of the network dataset. As each route is saved to its own feature class it is recording the cost impedances of the network dataset, as one can see in Figure 18 on line 42. The network dataset’s primary impedance is “T_Minutes” on line 41 (Figure 18). This entails that the route being solved always is determined by the shortest amount of minutes ArcMap spends traversing each feature in the network dataset. This can be set to other impedances such as finding the route that is the shortest in distance of feet or miles (“T_Feet” or “T_Miles”), as well as the route that spends the least on gasoline (“T_Domestic_Price” or “T_Imported_Price”) or train fare (“T_Cost”) per feature, but the fastest route by minutes is chosen for this analysis.

Following completion of the Python scripts for current and future routes, *Data Management*: Merge combines the two sets of 2,346 routes, respectively. Before joining them to the census tract feature class by their “ID” field relationship, the Fields “DriveAccessIndex” and “TrainAccessIndex” are added to the respective groups of merged routes created with and without the “DriveOnly” restriction turned on (“DriveAccessIndex” for “DriveOnly” restriction, and “TrainAccessIndex” without). These fields are calculated with Equations 8 & 9, respectively

in order to receive the system facilitated accessibility index. Following the field calculations, two newly merged route feature classes are joined to the census tract feature class through the *Data Management*: Add Join tool and the “ID” field relationship. Finally, as the census tract feature class now contains the appropriate fields, the percent change in system facilitated accessibility is calculated between the two system facilitated accessibility fields. Two new fields in the census tract feature class are made and named “Change” and “PercentChange.” The equations for calculating these fields are presented below using the prior field names mentioned in this section:

$$[Change] = [DriveAccessIndex] - [TrainAccessIndex] \quad (10)$$

$$[PercentChange] = [Change] / [DriveAccessIndex] \quad (11)$$

6.) Results

The LCPA results are displayed in Figure 14. The visualization of both corridors is not sufficient to determine which is least costly, in terms of length, most efficient in relation to the landscape, and safest, regarding who or what can be involved in an accident. Therefore, the *Spatial Analyst: Extract by Mask* tool is utilized to uncover quantifiable data to contrast the two. Using the corridor polylines representing the LCP and VTUSA HSR corridor, the Extract by Mask tool extracts the cost categories of raster cells under each corridor, and the results are displayed in Figure 19.

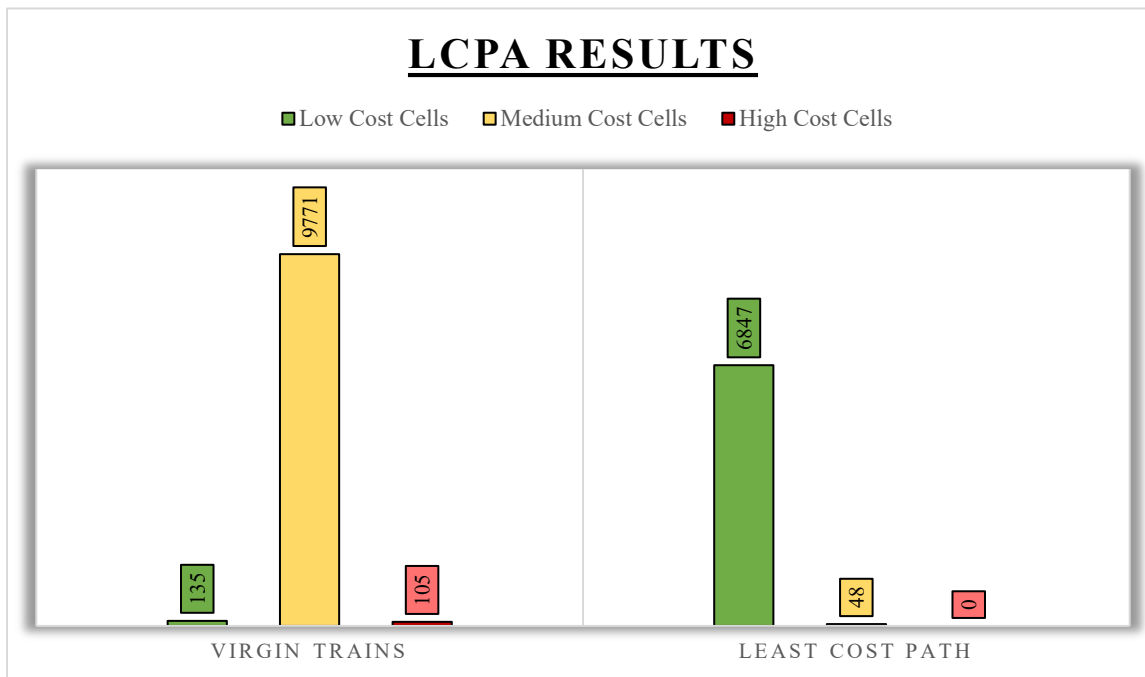


Figure 19 – A bar graph contrasting overall lengths and costs of the two corridors in Figure 14.

Based upon this study’s data and analysis, the VTUSA HSR corridor will accumulate 10,011 cells to reach the destination in Las Vegas. This is approximately 31% (3,116) more cells than

the LCPs more direct corridor, which accumulates to 6,895 cells in length. Figure 19 shows that the LCP corridor traverses considerably more low cost cells (6,847) than the VTUSA HSR corridor (135) at roughly a 1:51 ratio. It is also discernable that the LCP corridor traverse a significantly lower number of medium cost cells (48) than the VTUSA HSR corridor (9,771) at roughly a 1:204 ratio. The LCP corridor records no high cost cells as opposed to VTUSA HSR corridor which accumulates 105 cells at a high cost. The analysis results indicate that the LCP corridor is less costly in every category when contrasted to the VTUSA HSR corridor. Either corridor should strive to accumulate as many low cost cells as possible, while avoiding the medium or high cost cells and maintaining a shortest length as possible, in order to reduce overall costs of construction and maintain safety and increase efficiency.

The results of the SFAA are displayed as choropleth maps in Figures 20-22. Figure 20 displays the current state of system facilitated accessibility, determined by the level of effort it takes to drive to Las Vegas from any of the census tracts of Los Angeles County. Figure 21 presents that future state of system facilitated accessibility, due to the anticipated construction of a HSR between Victorville and Las Vegas. Finally, Figure 22 displays the percent change experienced at the census tract level when considering Figure 21 compared to Figure 20. Discernable from the data's attribute table from Figure 22, only six LA County census tracts experienced a negative percent change in system facilitated accessibility. This indicates that while a new HSR corridor can be created to improve the majority of LA County's system facilitated accessibility, there is still a small group of census tracts where one is better off driving to Las Vegas for the entirety of the journey. Figure 23 displays the census tracts that showed varying levels of improved system facilitated accessibility. In summary, 50.1% of census tracts experienced a 1-29% positive change in system facilitated accessibility, 38.8% experienced 29.1-

40% positive change, and 15.9% of census tracts experienced 40.1-99.86% positive change in system facilitated accessibility. No census tracts recorded 100% positive change in system facilitated accessibility, however, overall, 99.74% of the census tracts experienced an improvement to their Las Vegas system facilitated accessibility, justifying the VTUSA HSR project anticipated for 2023 based on the analysis presented here.

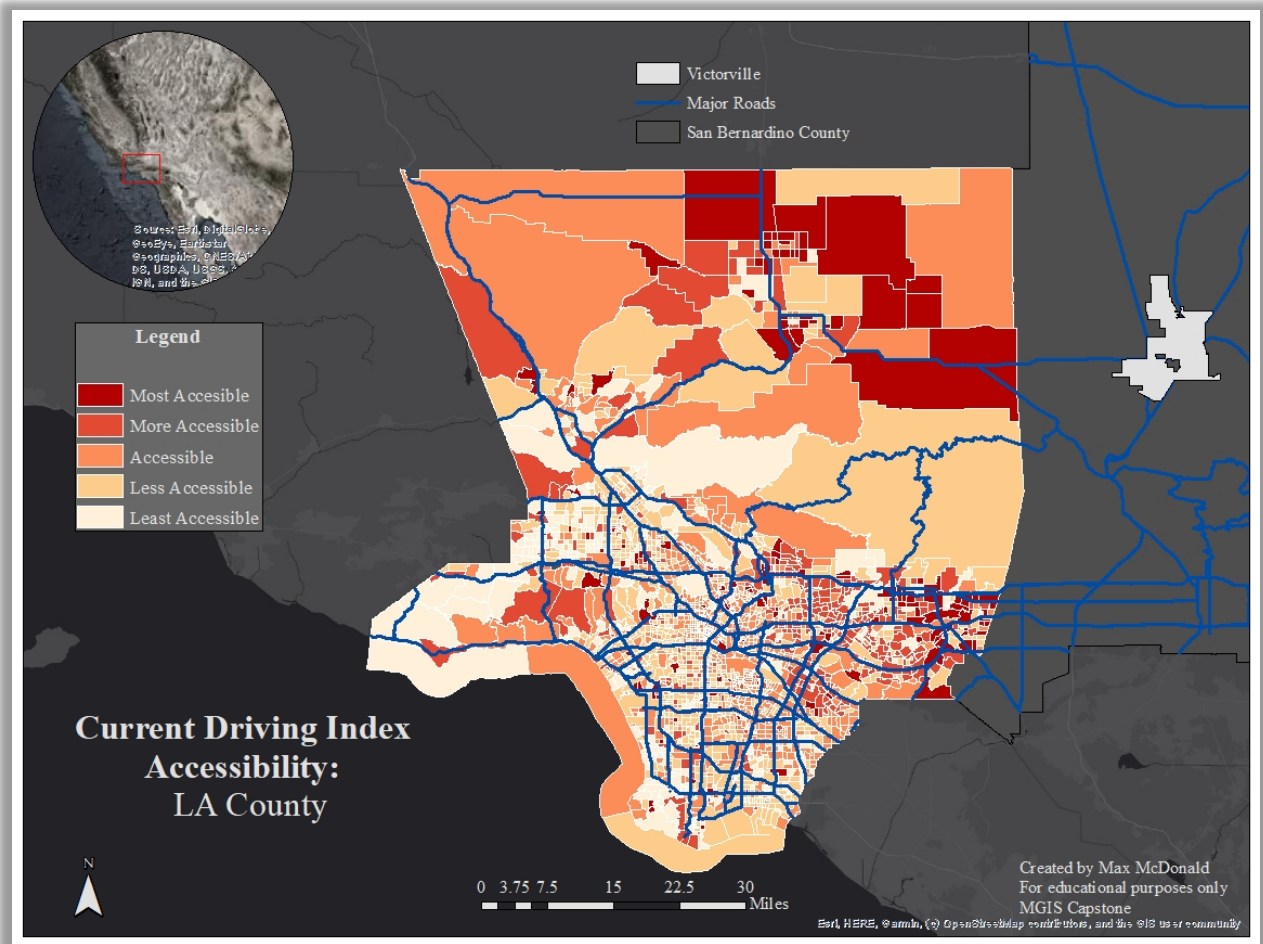


Figure 20 – Accessibility to Las Vegas by Driving.

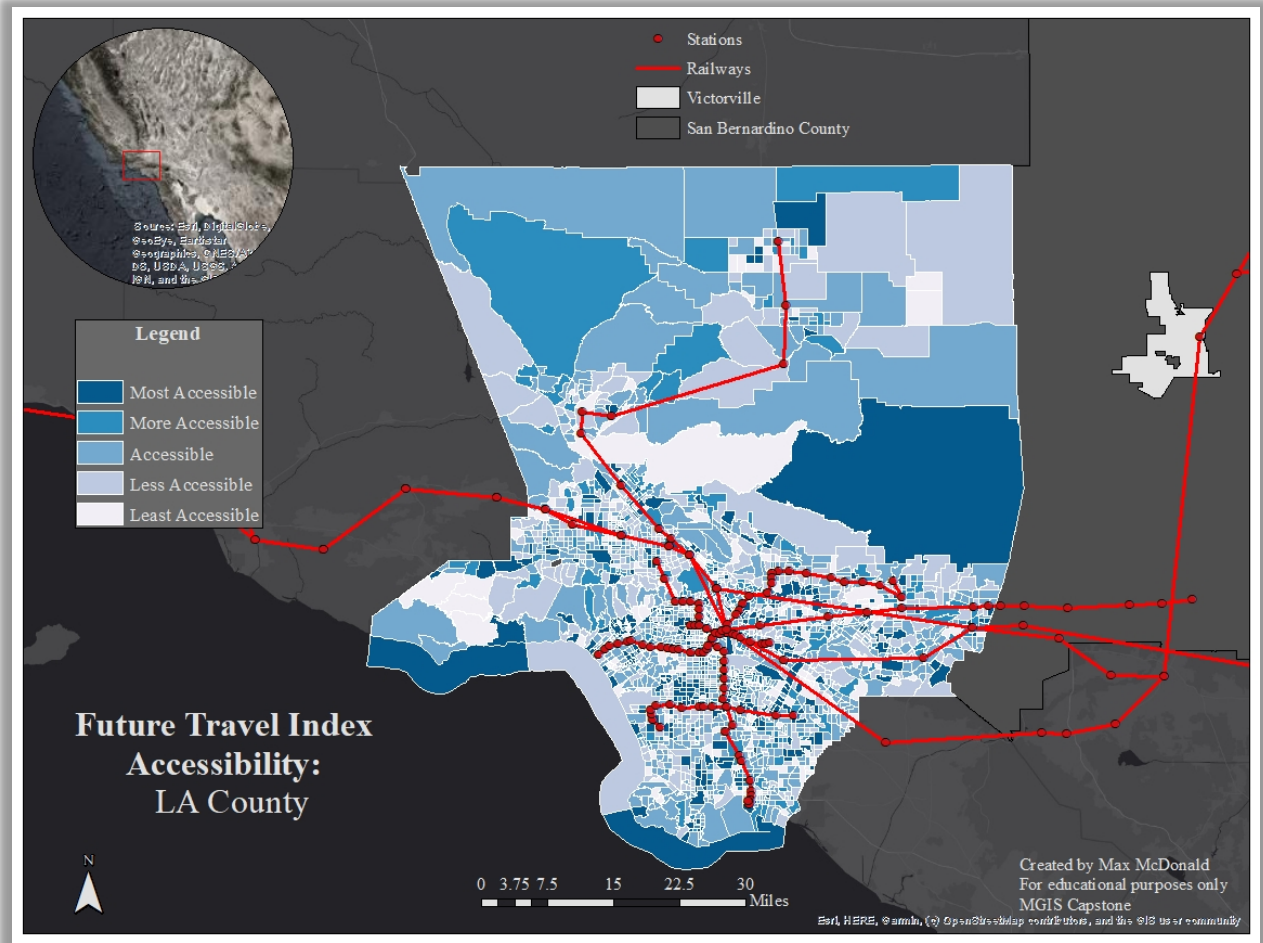


Figure 21 – Accessibility to Las Vegas with the option to Drive and/or take the train in 2023.

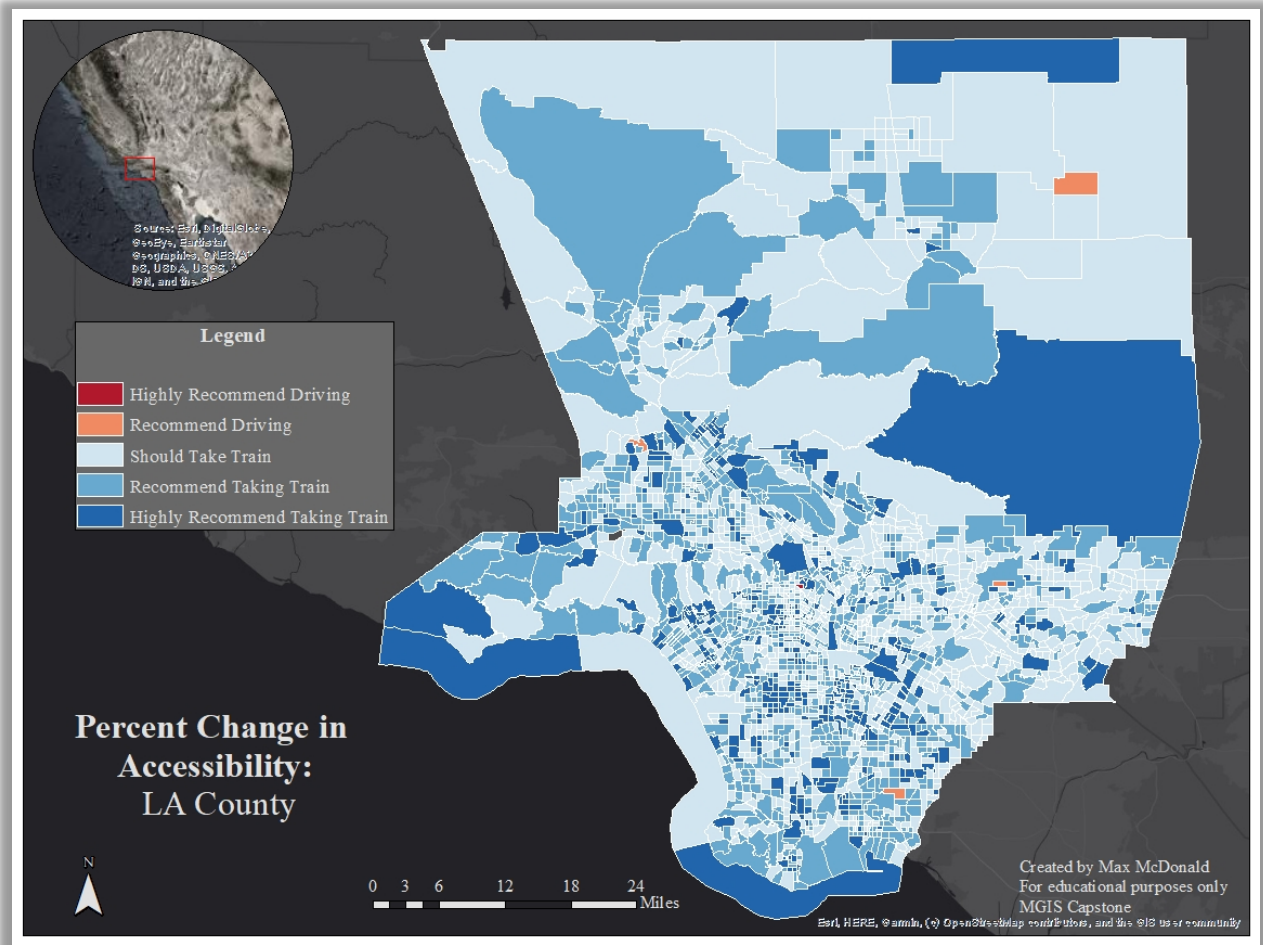


Figure 22 – The areas that are anticipated to incur major system facilitated accessibility improvement in 2023.

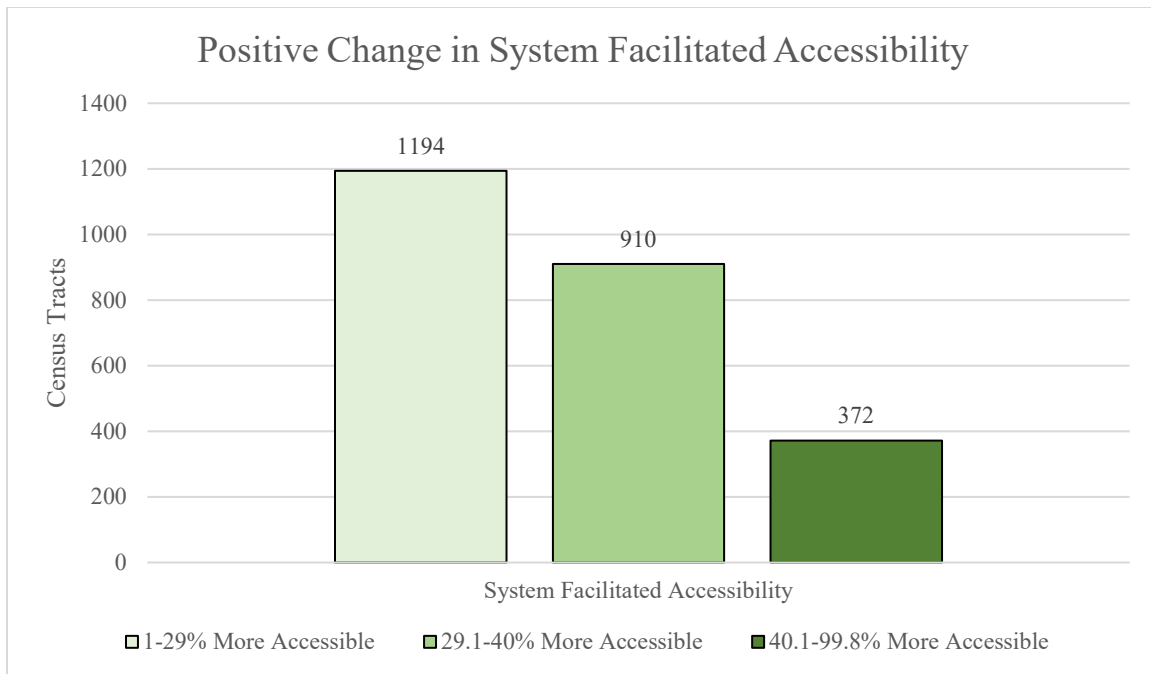


Figure 23 – The grouping of census tracts by improvement in system facilitated accessibility.

7.) Discussion & Conclusion

In this study, Esri’s ArcMap software is employed to accomplish two distinct objectives. The first objective is to propose an alternative least-cost path for the construction of a HSR project connecting two locations – Victorville and Las Vegas. The second objective is to visualize the current and future state of LA County’s system facilitated accessibility to Las Vegas with the anticipated VTUSA HSR. After collecting and formatting data, and performing geospatial analysis on that data, it is concluded that the LCP corridor in this study is stronger in all aspects when compared to the HSR corridor along I-15 that VTUSA is going to be constructing upon. Furthermore, the development of a HSR between Victorville and Las Vegas will prove to be extremely useful for the residents of LA County, with over 99% of the county’s census tracts experiencing increased system facilitated accessibility with its inclusion.

The LCP corridor proposed here stands as a testament to GIS as a useful tool for evaluating the cost, safety, and efficiency of linear infrastructure projects. This paper recognizes that there may or may exist political, socioeconomic, or other environmental factors that determine where exactly VTUSA is seeking and/or allowed to build their HSR, however, the employment of LCPA with appropriate/accurate data and stakeholder/expert influence, can discern a better corridor on a map. In addition to GIS serving as a tool for linear infrastructure planning and creation, GIS can assist in justification of such projects. While it is also recognized that no formal definition or measurement of accessibility exists within the literature presented in this study, one can understand from this study how the use of network datasets and system facilitated accessibility information can come together to perform a rapid assessment of the level of system facilitated accessibility one place has to another.

The analysis doesn't go without its limitations. Here, in a proof-in-concept exercise of AHP, no experts or stakeholders involved with such as project were consulted. In order for the criteria influencing the LCP to encompass the full scope of such a project, experts and stakeholders involved with the HSR must be consulted. Despite their absence, with the criteria chosen to influence the LCP through AHP-determined criteria weights, this study calculated a 24% consistency ratio based on their pairwise comparison ratings. This is 4-14% off acceptable according to Saaty's (1987) standards and leaves room for improvement within the AHP model. Likewise, other limitations of the LCPA exist due to the examination of the LCP corridor via the *Spatial Analyst*: Extract by Mask tool. Recall the individual cost surfaces that exist to create an accumulated cost surface with the *Spatial Analyst*: Weighted Overlay tool. If one were to run this tool upon the LCP and VTUSA HSR corridors against the "CostSurface_Slope" raster surface,

one would identify that the LCP corridor passes over a significant amount more of higher slope areas (Figure 24).

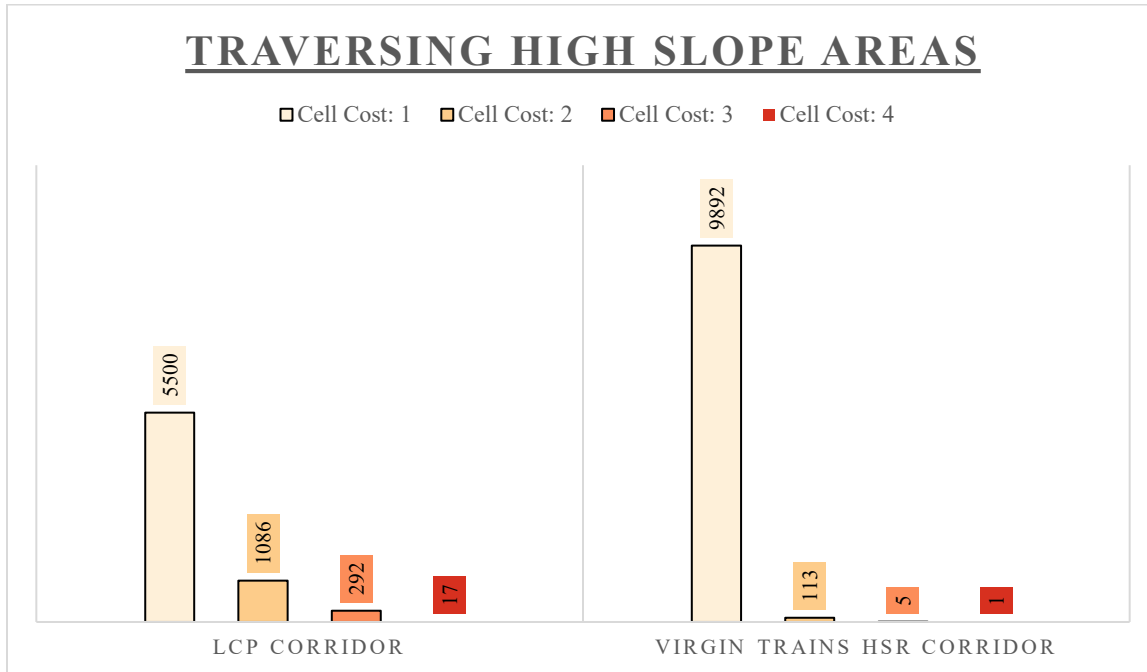


Figure 24 – Using the Extract by Mask Tool on the individual cost surfaces used to accumulate the accumulated cost surface shows the strengths or weaknesses of the LCP in each sub-criteria category.

This indicates a major weakness in the LCP as areas with high slope are not suitable for HSR construction or travel. The elevation data is from the USGS’ National Map and at a 1/3 arc-second resolution, therefore this weakness should be attributed to the proof-in-concept AHP determined criteria weights. In fact, at a more in-depth look of the remaining cost surfaces that contributed to the accumulated cost surface, extraction by mask concludes that the only criteria the LCP totally wins-out in all cost values are the Proximity to Infrastructure and National Park categories. The other two criteria regarding Road Types at Crossing and NLCD Land Cover classification indicate that the LCP is marginally better but still has room for improvement. Lastly, the LCPA is only as good as the quality of data procured for it. While the data used in

LCPA here is accurate and reliable, further data collection and quality control would certainly enhance the analysis and respective results.

In regard to the SFAA, a limitation of the network dataset stands as the most salient. Within the network dataset, impedance attributes like “Speed” and “Fare” (train ticket cost) can be made more accurate. Most importantly, there is only the assumption that the HSR fare VTUSA will charge will be \$20. Any increase or decrease in that amount, or changes to the other network dataset elements’ cost attributes will certainly alter the results presented in section 6. Furthermore, there exists no cost impedances for time constraints e.g. railway schedules, stop lights in traffic, as well as traffic itself. More sophisticated network datasets include one-way streets, live traffic data as well as wait-time penalties to accessibility when a user of the network must wait for a train to arrive. In this study, no such cost impedances or restrictions exist due to the absence of public information or lack of research on the author’s behalf. The network dataset also assumes that a user of the network is a single person rather than a group of people where costs less train fare’s can be split in a car-pooling manner, possible making driving to Las Vegas more accessible for some than others. Finally, the equations used to determine system facilitated accessibility are simplified and less in-depth than those presented in Barr et. al. (2015).

In spite of these limitations, the major next steps to improve an analysis such as this could be:

- 1.) Consult experts/stakeholders of VTUSA HSR project and request their input into the AHP model for defining criteria weights.
- 2.) Acquire more research and understanding of the exact location of VTUSA HSR and its one-way ticket cost.

- 3.) Incorporate more detailed network dataset data to provide a more reliable and accurate assessment of system facilitated accessibility, and
- 4.) Improve upon the equations used to determine system facilitated accessibility that account for value of time and coefficients of determination that afflict one's perception of accessibility versus the reality of it.

Until these improvements can be satisfied there is still a lot to learn from a study such as this.

The study represents a combinational-influence of the past attempts at LCP creation and accessibility measuring referenced in section 2. There exist many attempts to utilize GIS as a means to accomplish these objectives with or without taking responsibility for quantifiably evaluating the results. While results may look interesting or favorable on a map, one cannot be too sure of the outcome until the data is evaluated. Data-driven analysis facilitated by GIS is a popular method of operational research, but it is ultimately the diligent work of the end-users that justify the results.

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