12-2008

The Environmental and economic benefits of highway access management: A multivariate analysis using system dynamics

Dan Andersen
University of Nevada Las Vegas

THE ENVIRONMENTAL AND ECONOMIC BENEFITS OF HIGHWAY ACCESS MANAGEMENT: A MULTIVARIATE ANALYSIS USING SYSTEM DYNAMICS

By

Dan Andersen

A professional paper submitted in partial fulfillment
of the requirements for the

Master of Science Degree in Environmental Policy and Management
Department of Environmental Studies
Greenspun College of Urban Affairs

Graduate College
University of Nevada, Las Vegas
December 2008

Abstract

Better management of highway operations can be achieved, in part, by controlling vehicular access to adjacent properties and cross streets. This tactic, referred to as access management, has proven safety and operational benefits. However, doubts remain regarding its environmental and economic benefits.

I hypothesize that one environmental indicator, carbon emissions, will decrease with proper access management. Controlling access increases the speed at which vehicles travel, improving fuel efficiency and reducing carbon emissions. My hypothesis relative to financial impacts is that access management will neither help nor harm businesses. Controlling access can reduce travel time which has the effect of increasing the size of the market area for businesses located on that roadway, thereby increasing their customer base. This benefit may be off-set by the loss of some customers who are inconvenienced by limited access.

I used a system dynamics approach to test these hypotheses, following these five steps: articulate the problem, formulate a dynamic hypothesis, develop a simulation model, validate the model, and use it to evaluate policy options for addressing the problem. The model shows that the amount of carbon emitted per vehicle mile traveled decreases 0.25% with better access control. While this is a small amount, it equates to a 185 kg/day reduction in carbon emissions along one sample roadway segment, and over 5,000 metric tons per year from the entire Las Vegas Valley. The model helps us to understand how access management impacts adjacent businesses, however the degree to which they are impacted is inconclusive. In order to accurately model these impacts we need better data on the portion of customers that would be deterred from visiting a business because of reduced access.

Table of Contents

Tables

Figures

Acronyms

AADT	average annual daily traffic
CO2	carbon dioxide
DOE	US Department of Energy
EPA	US Environmental Protection Agency
GIS	geographic information systems
HEC	Hydrologic Engineering Center
MPG	miles per gallon
MPH	miles per hour
NCHRP	National Cooperative Highway Research Program
NDOT	Nevada Department of Transportation
RTC	Regional Transportation Commission of Southern Nevada
TRB	Transportation Research Board
TWLTL	two-way left turn lanes
UNLV	University of Nevada, Las Vegas
V/C	volume/capacity

1. Introduction

Better management of highway operations can be achieved, in part, by controlling vehicular access to adjacent properties and cross streets. This tactic, referred to as access management, has proven safety and operational benefits (Transportation Research Board [TRB] 2003), however, the leading transportation research agency in the United States, the Transportation Research Board (TRB) acknowledged that research conducted to date on the environmental and economic impacts of access management is limited (TRB 2007). The TRB has initiated a new research project: "Determining the Economic Value of Roadway Access Management" (TRB 2007).

1.1 Research Questions

There are several techniques used to control access, including limiting the number of driveways, installing raised medians, limiting the number of traffic signals, spacing traffic signals, use of exclusive turning lanes, and implementing landuse policies that influence the type of development adjacent to a roadway. My research focuses on the effects of the first two techniques: limiting the number of driveways and installing raised medians. The primary question I seek to answer through this project is how these two access management techniques affect air quality and the financial performance of businesses that front the roadway.

From available research we know that traffic congestion increases carbon emissions, and we know that access management reduces traffic congestion. Therefore, we can assume that good access management will reduce carbon emissions, but to what extent can the two access management techniques studied here reduce carbon emissions?

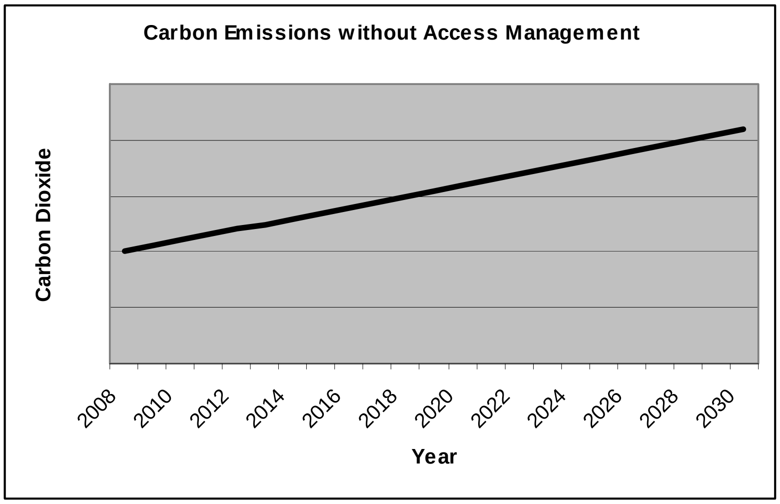
Changing or restricting how property owners can access their property, or worse, how customers can access businesses, is usually met with great opposition. We need to know if access management has a negative impact on businesses. Will fewer customers visit a store because there are fewer driveways to that store, or because there is a center median prohibiting left-turns?

Transportation engineers and planners around the US have requested tools for communicating the benefits of access management, needed to develop public support for such policies (TRB 2008). Are there other benefits of access management that we can communicate to help reduce public resistance?

1.2 Hypotheses

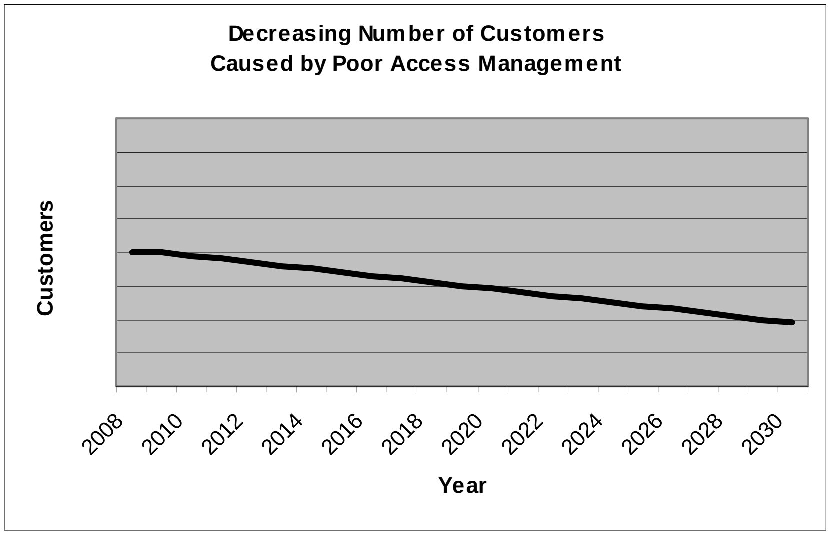
Relative to the effect that access management has on the environment, my hypothesis is that uncontrolled access slows the speed at which vehicles travel, reducing fuel efficiency and increasing carbon emissions. Therefore, controlling access by limiting the number of driveways and installing center medians will reduce the total amount of daily carbon emitted from vehicles using a given roadway. Without knowing exact values, I hypothesize that carbon emissions will increase at a gradual rate in relation to traffic congestion, as shown in Figure 1.

FIGURE 1
Reference Mode: Carbon Emissions in the Absence of Access Management



Relative to financial impacts to businesses, I hypothesize that limiting the number of driveways and installing center medians may cause an initial and temporary dip in customers, but over time will have no impact to local businesses that do not rely heavily on drive-by traffic. Uncontrolled access slows the speed at which vehicles travel, increasing the time it takes to travel to a particular destination on that roadway. Increased travel time has the effect of reducing the size of the market area of the businesses located on that roadway. Therefore, reducing the market area reduces the number of customers that will visit the store. Figure 2 illustrates this gradual reduction in customers that may occur as a result of poor access management. Controlling access increases the market area and market population. A portion of customers may be lost due to the inconvenience of reduced access, off-setting the potential increase in customers gained from increasing the market area. As the portion of drive-by customers increases, the potential for losing them due to the inconveniences caused by access management increases. Therefore, stores that rely on drive-by customers will be negatively impacted by access management, while stores with a more loyal customer base will not be negatively or positively impacted by access management.

FIGURE 2
Reference Mode: Decreasing Number of Customers Caused by Poor Access Management



2. Research Method

This study follows a system dynamics approach to examine these questions. I will first describe various modeling approaches, why I selected system dynamics, and the software program I used. This is followed by a detailed description of the standard system dynamics approach as I applied it to this project.

2.1 Modeling Approaches and Software Considered

There are various approaches to modeling the effects of access management. Conceptual models—written or verbal descriptions—are used to explain theories, but lack quantitative evidence. Physical models, such as maps and figures, can help illustrate theories, but still lack the quantitative analysis that computer models provide. The two most common computer models used in engineering are static and dynamic, described below.

2.1.1 Static Modeling

Models are frequently used in the field of engineering to solve complex problems—to find the best, and sometimes only solution. The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers has developed several programs for modeling precipitation runoff, reservoir operations, river hydraulics, sediment transport, and related surface and groundwater hydrology (U.S. Army Corps of Engineers, 2008). Other civil engineering models are used for modeling systems such as air dispersion, traffic patterns, and water and wastewater distribution and treatment processes. Some are simple spreadsheet models while others are unique software programs. Most engineers, at some point in their education or work experience, have used models, and many use them on a regular basis.

Some of these models are static models. Bob Diamond, president of Imagine That Inc., a modeling software company, offers a definition of static models (2008):

"Static models describe a system mathematically, in terms of equations, where the potential effect of each alternative is ascertained by a single computation of the equation. The variables used in the computations are averages. The performance of the system is determined by summing individual effects. Static models ignore time-based variances. Also, static models do not take into account the synergy of the components of a system, where the actions of separate elements can have a different effect on the total system than the sum of their individual effects would indicate."

Historically, civil engineering focused on design-related problems, whose solution could often be derived with static models. Engineers are now called on to solve any number of challenges, including developing management strategies and policies that guide engineering solutions. New tools are needed to understand the complex systems that influence policy and managerial options.

2.1.2 Dynamic Modeling

In a complex system, like highway operations, a change in one variable will cause a change in another which ripples through the system and returns to influence the original variable. This effect is called feedback. System dynamics describes that feedback and the dynamic relationships, and models them to simulate the effects of implementing various policies. Diamond provides a definition of dynamic modeling (2008):

"Dynamic modeling is a software representation of the dynamic or time-based behavior of a system. While a static model involves a single computation of an equation, dynamic modeling, on the other hand, is iterative. A dynamic model constantly recomputes its equations as time changes. Dynamic modeling can predict the outcomes of possible courses of action and can account for the effects of variances or randomness. You cannot control the occurrence of random events. You can, however, use dynamic modeling to predict the likelihood and the consequences of their occurring."

The field of system dynamics was founded by Jay Forrester, aided by the advent of computer technology that made it possible to model complex systems. In 1956, Professor Forrester started the System Dynamics Group at the Sloan School of Management, at Massachusetts Institute of Technology. He wrote the first book on the subject, *Industrial Dynamics,* in 1961. Today system dynamics is used in a variety of disciplines, as noted by the System Dynamics Society (2008), such as:

- "corporate planning and policy design,
- public management and policy,
- biological and medical modeling,
- energy and the environment,
- theory development in the natural and social sciences,
- dynamic decision making, and
- complex nonlinear dynamics"

2.1.3 Software for Creating System Dynamic Simulation Models

In 1985, two companies developed the next generation of computer-based system dynamics modeling programs based on the structure of stocks and flows developed by Jay Forrester. Ventana Systems created Vensim (Vensim 2008), and High Performance Systems (they later changed the name to isee systems) developed Stella (isee 2008). Both have evolved over time and are in wide use today. Powersim Software (Powersim 2008) later introduced a similar platform which is also capable of integrating with geographic information systems (GIS) for simulating geographical data over time.

Material and information flow into and out of stocks, where they accumulate over time. Traditional system dynamics modeling software, such as Vensim, Stella, and Powersim, use an icon to represent each stock. The rate at which material and information enter and exit each stock is represented by a “flow” icon. Any number and type of variables may influence, or be influenced by, the stocks and flows. Arrows connect the icons and show the direction of influence. These three icons can be used to represent the structure of any system, which makes it easy for anyone familiar with the basic concepts of system dynamics to understand the model.

Other programs released in the past decade incorporate more graphics in an effort to make it easier for those unfamiliar with system dynamics to understand the structure of the model and the formulas that define it. In 1999, GoldSim introduced a graphical simulation program that combined three types of modeling: system dynamics, discrete simulators, and probabilistic modeling (GoldSim 2008). I developed the access management simulation model for this project using GoldSim software. GoldSim uses many different icons, called elements, to represent the components of the system being modeled. The system is shown schematically and can incorporate graphics. Each element of the system can be opened to view the formulas and relationships. This object-oriented graphical interface is helpful for showing model logic.

2.2 System Dynamics Approach to Modeling Access Management

The system dynamics process I followed, as described by John Sterman (2000), involves five steps: articulate the problem, formulate a dynamic hypothesis, develop a simulation model, validate the model, and use it to evaluate policy options for addressing the problem.

2.2.1 Problem Articulation

More cars and trucks are using our highways than they were designed to hold, leading to more crashes, traffic congestion, air pollution, and time spent behind the wheel. The most common solutions to this problem are: increasing the capacity of highways, reducing the number of vehicles on the road, and better management of highway operations.

Increasing capacity is accomplished by building more roads or expanding the ones we have. This helps, but is expensive, not sustainable, and environmentally damaging. The number of vehicles on the road can be reduced by getting people to leave their cars at home and take public transit or join a car pool. This option is the most environmentally friendly and sustainable solution, but the least convenient. Public transit is also costly, both in terms of the initial capital expenditure and ongoing maintenance and operations.

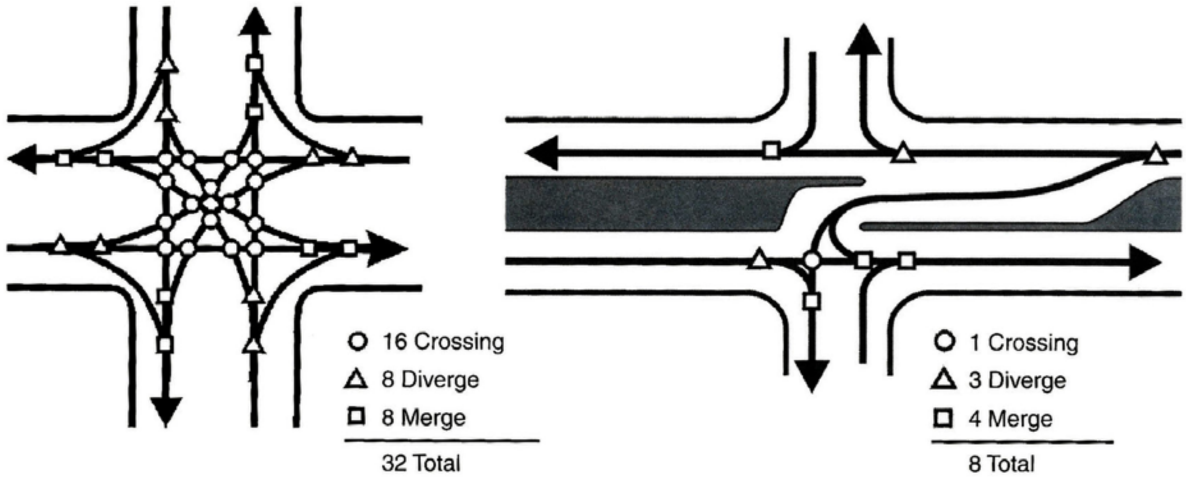
Better management of highway operations can be achieved, in part, by controlling vehicular access to adjacent properties and cross streets. This tactic, referred to as access management, is relatively effective and economical. State and local agencies are searching for solutions to transportation problems that offer the greatest return on their investment, especially in the face of declining tax revenues resulting from the 2008 economic slowdown.

2.2.1.1 What is Access and When is it a Problem?

Driveways and cross-streets provide drivers access to a roadway. If a driver is able to enter or exit a driveway from any direction, that driveway has full access to the adjacent road. Roads that have a raised center median separating opposing lanes of traffic, in front of a driveway or at a cross-street, prevent left turns into and out of that driveway or cross-street, and therefore limit the access at that point.

Everywhere two roads or a road and driveway meet, there are opportunities for vehicles to collide—called conflict points. Figure 3 illustrates the number of conflict points at a four-way intersection with and without a median. An intersection with full access has 32 conflict points, versus only 8 at an intersection with a directional median opening, which offers some access by allowing U-turns and left turns into the cross-street. A closed median at this intersection would only have 4 conflict points—possible rear-end collisions caused when a vehicle makes a right-in or right-out turn.

FIGURE 3
Reduction in Conflict Points (TRB 2003)
Vehicular conflict points at a typical four-way intersection versus a directional median opening.



Even if vehicles don't crash at a conflict point, they often have to slow down to avoid a collision, thus slowing the flow of traffic. This slowdown creates the congestion that we all observe, reduces fuel efficiency (US Environmental Protection Agency [EPA] 2008), and increases emissions of greenhouse gases (Frey, et. al. 2001) which are not as immediately discernable.

Imagine a roadway with several driveways and cross-streets in close proximity. The conflict points at each point of access would overlap and grow significantly. To illustrate, I was recently visiting the town of Portales, New Mexico, and observed a 5-legged intersection surrounded by several driveways in close proximity, illustrated in Figure 4. Standing on the northeast corner of Avenue I and 1st Street, I witnessed a northbound car on Avenue I and a northbound car Avenue G play a game of chicken to see which could cross 1st Street first, and continue north on Avenue I. The two drivers had to be aware not only of each other and the cross traffic on 1st Street, but of other drivers entering and exiting from nearby driveways and cross-streets. I counted a total of 18 access points within two blocks, and didn't attempt to count the conflict points. This intersection has one of the highest crash rates in Portales. Traffic volumes are not very high in Portales, so it is difficult to gauge the effect that poor access management has on operations.

FIGURE 4
5-Legged Intersection
Within one block, 1st Street in Portales, NM, has 11 access points and an additional 7 close-by on cross-streets, shown in red dots. The photograph was taken from the NE corner of 1st Street and Avenue I.

2.2.1.2 How is Access Managed?

Managing access involves controlling the number and spacing of driveways and cross-streets, and the type of access provided to each. For example, a reasonable approach to managing access at the 5-legged intersection in Portales could include closing Avenue G at 1st Street, consolidating the driveways at the parcel on the southwest corner of 1st Street and Avenue I, and where possible, moving driveways away from the intersection. This would reduce by a third the number of access points from this area and still provide ample access to the church, car wash, store, laundromat, and apartment complex located at each of the five legs of this intersection. Additional driveway consolidation would only be necessary if crashes, volumes and congestion were very high or projected to increase significantly.

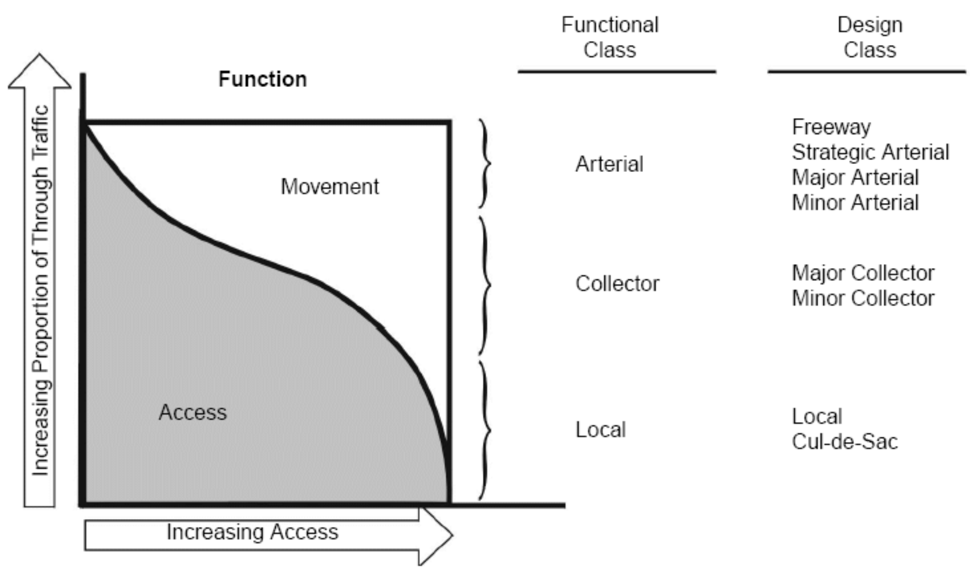
Another access management technique is the use of median treatments, including two-way left turn lanes (TWLTL) and raised medians. Two-way left turn lanes mitigate and reduce the effects of conflict points by removing left-turning vehicles from through traffic lanes, therefore providing some safety and mobility benefits, however they do not reduce the number of conflict points. Only raised medians reduce the number of conflict points. Directional median openings typically allow left turns and U-turns to vehicles traveling on the primary arterial, and prohibit vehicles turning left in to the arterial from a driveway or cross-street. A fully closed median prevents all vehicles from crossing the primary arterial and making any left turn movements.

Another technique involves the adequate spacing and timing progression of traffic signals. Even when signals are linked together in a computerized network, it is very difficult to time their progression when signals are too close together and not evenly spaced. Other techniques are generally related to these and include use of exclusive turning lanes, use of service and frontage roads, land use policies that limit right-of-way access to highways, and separation of conflict points to reduce driver workload. My study focuses on the most common access management techniques of installing closed medians and controlling driveway spacing.

2.2.1.3 Balancing Access and Mobility

All of these techniques require a supporting street network to create alternate access. A road through a residential neighborhood has a much different purpose than a freeway or an urban arterial. Each roadway in a transportation network is assigned a functional classification which designates the level of access it should provide and its priority within the network. Local residential roads are allowed full access, and therefore have limited mobility, while major highways and freeways are allowed very little access and therefore offer greater mobility. Figure 5 illustrates the negative correlation between access and mobility—as access decreases, mobility increases—and the types of functional classifications associated with each. In the case of Portales' 5-legged intersection, Avenue G is a local road, Avenue I a collector, and 1st Street an arterial. Each serves a different purpose and should have differing levels of access, although at present that is not the case.

FIGURE 5
The Compromise between Access and Mobility (TRB 2003)



2.2.1.4 Existing Research on the Effects of Access Management

A significant amount of research has been conducted on the effects of access management since the 1970's. The most comprehensive of these was conducted by the Transportation Research Board, and published in the "Access Management Manual" which includes a compendium of the prior research (TRB 2003). According to the TRB, access management has an effect on safety, operations, economics, and the environment. The TRB cites several studies to describe and quantify each of these effects. For purposes of this study, only one methodology for quantifying the effect of each area impacted was selected and is summarized below.

Safety

Numerous studies have shown that the crash rate increases proportionately with access density—the number of driveways per mile. One study calculated that "crash rates generally increase by the square root of the change in access density. Thus, an increase from 10 to 20 access points per mile would translate into about a 41% increase in the crash rate (Levinson 2000, TRB 2003).

Roadways with continuous two-way left-turn lanes (TWLTL) are safer than undivided roadways, while the safest roadways have nontraversable center medians. On average, "the crash rate on roadways with a nontraversable median is about 30% less than on those with a TWLTL" (Gluck, Levinson, Stover 1999; and TRB 2003).

Operations

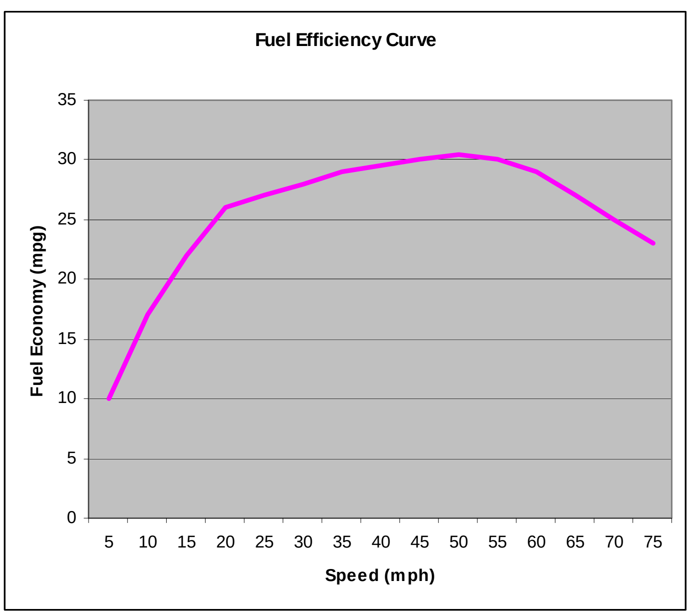
Once the volume of vehicles using a roadway exceeds the free-flow capacity of that roadway, it is congested. Congestion is measured in terms of volume/capacity (V/C). As V/C increases, travel time on that roadway and the likelihood of vehicles crashing into each other increases. Uncontrolled access further increases the travel time and crash rate. Vehicles turning off of a highway must slow down to safely negotiate the turn, and as they do so, vehicles behind them must also slow down. Numerous access points on a highway, result in numerous opportunities for turning vehicles—slowing down the flow of traffic. One study calculated that the overall free-flow speed is reduced by 0.15 mph per access point (Reilly et. al. 1989 and TRB 2003).

Traffic signals also slow traffic significantly. The reduction in travel time for an average arterial in Las Vegas, Nevada is approximately 20 seconds per traffic signal. This is based on calculations from Las Vegas' Regional Travel Demand Model. The formula was modified from the Highway Capacity Manual and is based on the posted speed, signal cycle length, green time, and signal progression on a 2-way grid (Parsons 2007).

Environment

Vehicles traveling at slower speeds, and in start and stop conditions, consume more fuel and emit more pollutants. The operational benefits of access management, described above, translate into better fuel efficiency and fewer emissions. Carbon emissions are directly linked to fuel efficiency. The more fuel efficient the vehicle, the less carbon, and other pollutants, are emitted into the environment. The US Department of Energy (DOE) and the Environmental Protection Agency (EPA) sponsor the website www.fueleconomy.gov to promote fuel efficient vehicles and practices. They cite a study that states that the average vehicle achieves the greatest fuel efficiency at 60 mph (West, et. al. 1999, and DOE and EPA 2008). At speeds slower and greater than 60 mph, vehicles consume more fuel, as illustrated in Figure 6.

FIGURE 6
Fuel Efficiency Curve (West, et. al. 1999, and DOE and EPA 2008)



The US EPA posts a Greenhouse Gas Equivalencies Calculator on their website (EPA 2008) for calculating, among other things, the carbon emissions generated from burning a gallon of gasoline—approximately 8.8 kg/gallon. Therefore, knowing the average number of vehicles traveling a highway and the average speed at which they travel, we can estimate the total amount of fuel consumed and carbon emitted. While not terribly accurate, this simple method of calculating emissions is useful for comparative purposes and can be applied to any roadway. The EPA has much more precise computer models for estimating emissions from various vehicles, sources, and fuels under differing conditions, when those parameters are known and available.

Economics

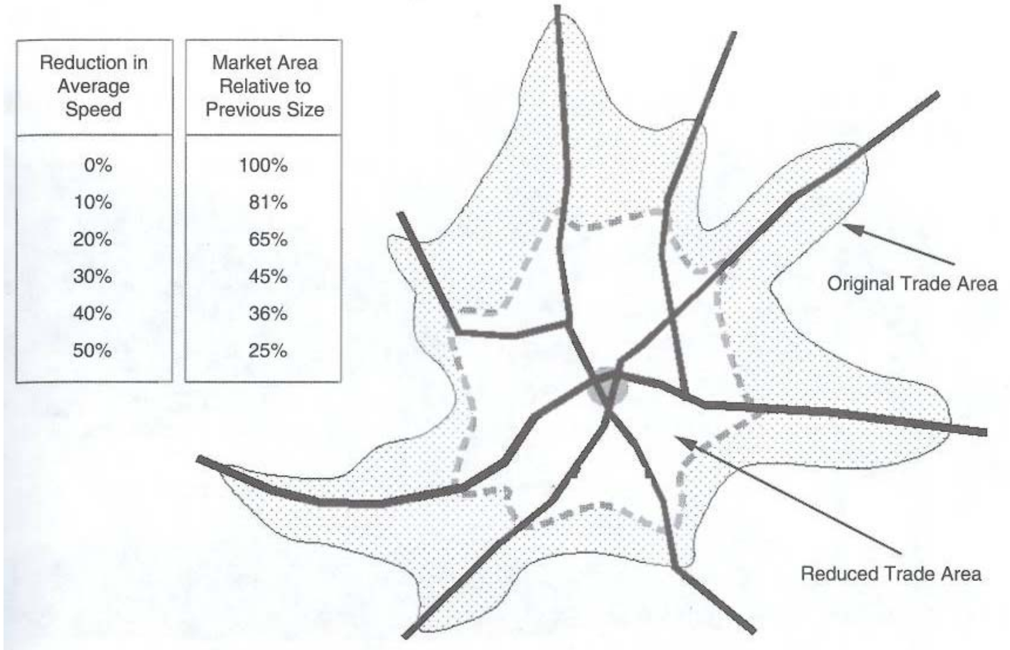
The economic effects of access management are the most difficult to quantify and the most controversial. Access management is often perceived to be economically adverse to businesses because its goal is explicitly to limit access, which most equate with limiting a customer's access to businesses adjacent to the roadway. Business owners want to make it as easy as possible for customers to get to their business, by providing multiple driveways with unrestricted access, and if possible, by installing traffic signals in front of their business. Most feel that restricting their access will hurt their business.

On the other hand, there is anecdotal evidence that a lack of access management can contribute to the economic decline of a business corridor. Similar to the tragedy of the commons, a roadway is a common area available to all, but with limited capacity. For a time, each business can have an unlimited amount of access to the highway without adversely affecting the highway. At some point however, the highway reaches its capacity and each additional unrestricted access point slows traffic and increases the number of crashes. Congestion reaches a level that drivers begin to avoid the highway, when possible, and shop at businesses located on other roadways that are safer and less congested. All businesses along the congested roadway suffer when that occurs. To correct this, all business must agree to share the resources of the highway by equally restricting their access. Landscaped medians not only provide operational and safety improvements, but can beautify a business corridor and support revitalization.

Beginning in the 1990's, several states, most notably Kansas, Texas, Florida, and Iowa, began studying the economic impacts of installing raised medians and consolidating driveways (TRB 2003, Maze 1997, Eisele and Frawley 1999). These studies showed that in implementing access management had no economic impact to most businesses. However, businesses that rely heavily on pass-by customers, such as gasoline stations, experienced a drop in sales after their access was restricted. In some cases, the value of adjacent properties increased following improvements to access. These studies were primarily based on survey results, and did not provide sufficient detail to quantify the economic impacts of access management.

One study showed a quantifiable relationship between travel time and the size of the market area. "Market area analysis demonstrates that increases in average travel times translate into longer commute times and reduce the market area for businesses" (TRB 2003, Stover and Koepke 1988). Figure 7 illustrates this effect.

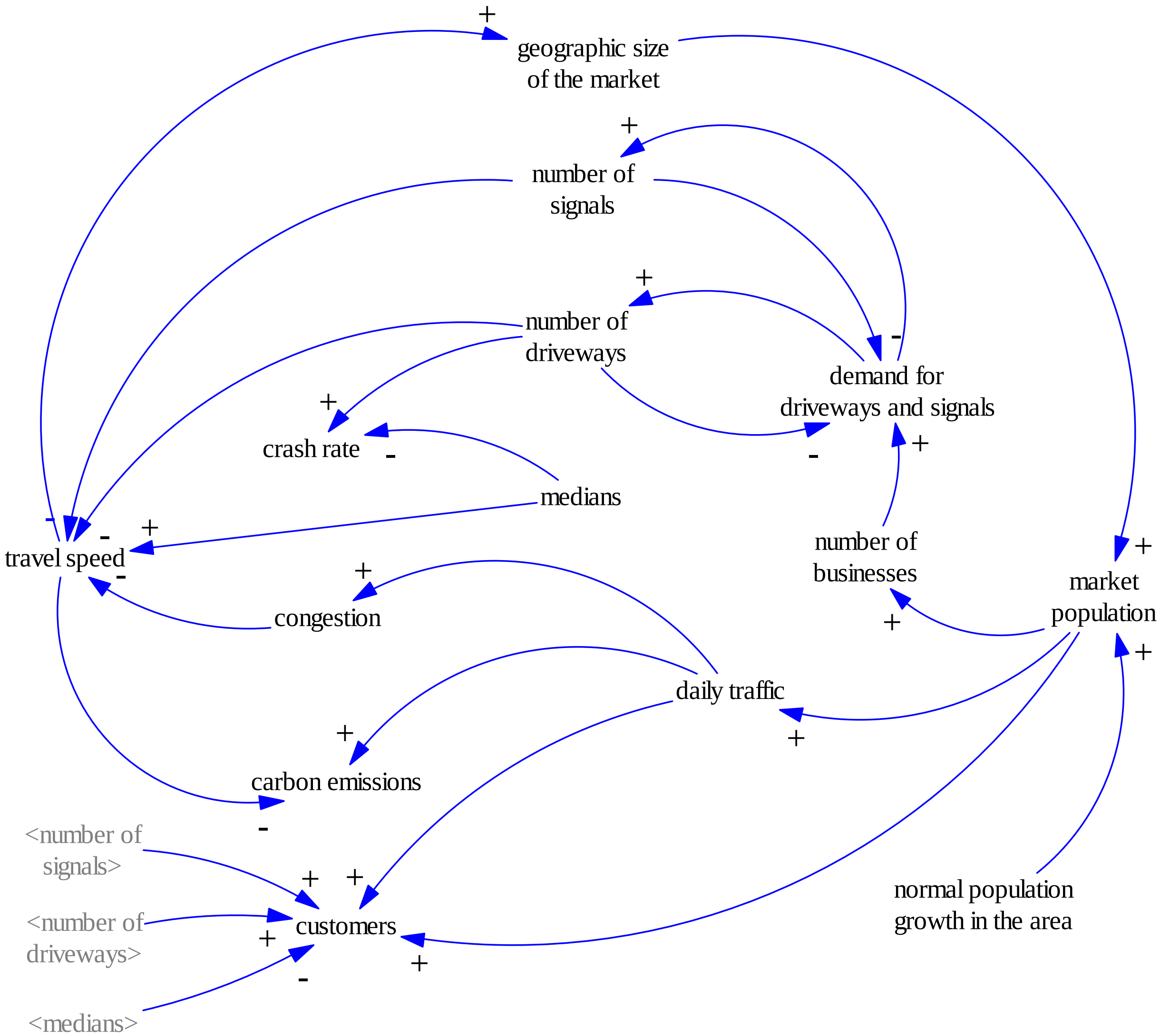
FIGURE 7
Effects of Travel Time on Market Area (TRB 2003, Stover and Koepke 1988)



2.2.2 Dynamic Hypothesis

The dynamic hypothesis is developed to describe the structure of the system that is causing the problem under consideration. This is typically accomplished with a causal loop diagram which displays the relationships of the variables within the system. The causal loop diagram for this study is shown in Figure 8 and described below.

FIGURE 8
Causal Loop Diagram



The crash rate is influenced by the presence or absence of medians, and the concentration of driveways and signals. Installing medians is a policy decision, and therefore not directly influenced by other variables. There is an interesting loop affecting the number of driveways and signals. As travel speed increases, the market area increases, which results in an increase in the market population and therefore the number of business along the roadway. This has the effect of increasing the demand for driveways and signals. If the demand for driveways and signals exceeds the existing number, then more are added which reduces the travel speed, market area and population, and puts downward pressure on the demand for more driveways and signals. This is called a balancing feedback loop—alternating pressures keep it somewhat balanced. Finding which has a stronger pull is determined when these relationships are quantified.

Congestion is part of a similar balancing loop. In the absence of congestion, travel speeds increase, increasing market area and population, and daily traffic counts. The increased traffic increases congestion, reduces the speed, market area and population, and eventually the daily traffic.

Carbon emissions are part of the same feedback loop with congestion, only in this model, increased emissions don't affect other variables. In reality, emissions could reach a point where they influence the desirability of the area and therefore the population, but that would likely be over a longer time period than the parameters of this model. Federal transportation funding would be reduced if emissions exceed federal air quality standards, but financial impacts are also outside the parameters of this model.

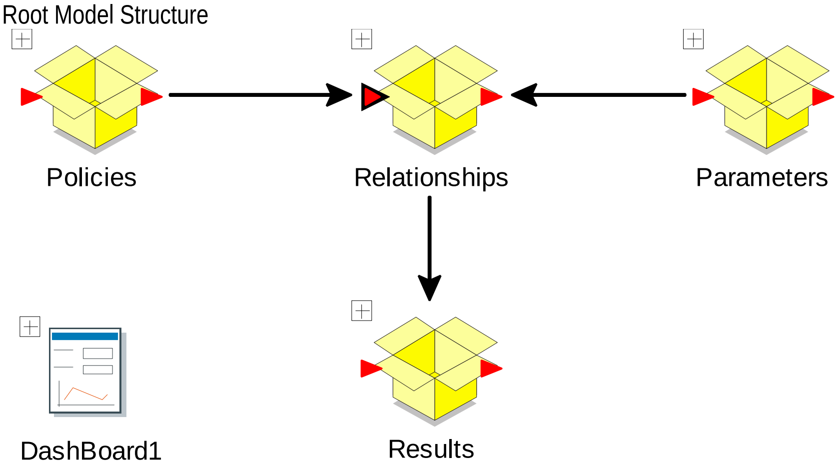
Customers are also part of the same feedback loop with congestion and carbon emissions, in that they are affected by the volume of daily traffic. In addition, as access is increased with more driveways and signals, the number of customers increases; and as medians are installed, the number of customers decreases.

The market population will grow (or decline) according to the normal population growth (or decline) in the area—even if the geographic size of the market remains unchanged. A decline in the geographic size of the market, due to a decline in travel speed, could cancel out the normal population growth in the area. Conversely, an increase in the geographic size of the market could accelerate the normal population growth.

2.2.3 The Simulation Model

In order to test the dynamic hypothesis to see if the model reproduces the behavior I anticipate, I developed a simulation model using GoldSim. I assigned values to each of the variables shown in the causal loop diagram (Figure 8) and developed formulas to describe their relationships with each other. GoldSim uses a hierarchal structure of containers and sub-containers to organize the model. The root containers in my model include parameters, relationships, and policies, as shown in Figure 9. The model parameters contain the values of the data used to describe the current conditions of the roadway segment I am testing. The relationships container houses the formulas that quantify all of the relationships among the variables. The policies container includes policy levers used to manipulate the model, to test various policy options. The dashboard is used to run the model, and the results container holds graphical outputs of each model run.

FIGURE 9
Root Model Structure



2.2.3.1 Model Parameters

Most of the data that I used came from a study I am managing at CH2M HILL, for the Regional Transportation Commission of Southern Nevada (RTC) (CH2M HILL 2008).

We collected data on 75 segments of arterial roadways, each approximately 7 miles in length, throughout the Las Vegas Valley. A description of the type of data collected, and the source for each, is shown in Table 1.

TABLE 1
Type of Data Collected on Each Segment

Characteristic	Description	Source
Average V/C	Weighted average of V/C	RTC Travel Demand Model
Average Speed	Weighted average of posted speed limits	RTC Travel Demand Model
Signals/Mile	Total number of signals divided by the segment length	RTC
Driveways/Mile	Total number of driveways divided by the segment length	RTC
Average Volume	AADT averaged from NDOT traffic count locations along the segment.	NDOT and RTC
Raised Median	Percent of the segment with raised median.	Visual inspection using Google Earth aerial photographs.
Crashes/Mile	Gross number of crashes from 2002 to 2006, divided by the segment length.	UNLV, Transportation Research Center

Three segments were selected for testing in the simulation model. Cheyenne Avenue East had fairly average characteristics. Charleston Boulevard East is an older, built-out segment with an above average number of driveways, signals, congestion, crash rate and other characteristics. Commerce Street is less developed and has below average characteristics. The characteristics of the selected segments, and the minimum, maximum, and mean for the entire sampling of 75 segments are shown in Table 2. I first developed a model using the parameters for the Cheyenne East segment. Once the Cheyenne model was complete, I made two copies of it and changed the parameters to match those of Charleston and Commerce.

TABLE 2
Arterial Segment Characteristics

Segment	Length (miles)	Average V/C	Average Posted Speed (mph)	Signals	Driveways	Average Annual Daily Traffic (AADT)	Percent of Segment with Raised Median	Crashes (5-year total)	Vehicle Miles Traveled (VMT)
Cheyenne East	5.5	0.72	45.5	14	112	39,122	25%	2,359	216,661
Charleston East	6.8	0.76	41.9	19	273	48,900	48%	5,155	332,482
Commerce	6.4	0.49	32.8	4	63	10,070	4%	482	64,130
Min	2.2	0.07	25.9	0	15	140	0%	75	429
Max	11.9	1.17	49.7	34	428	59,763	100%	8,086	511,668
Average	7.3	0.61	38.9	13	149	25,605	38%	2,300	196,149

CH2M HILL also collected population projections in 0.5-, 1.5-, and 3-mile radii around each segment, to the year 2030 (CH2M HILL 2008). I input this data into a 2-D table in the model and used it to estimate population in a given year and according to the geographic size of the market area, shown in Table 3.

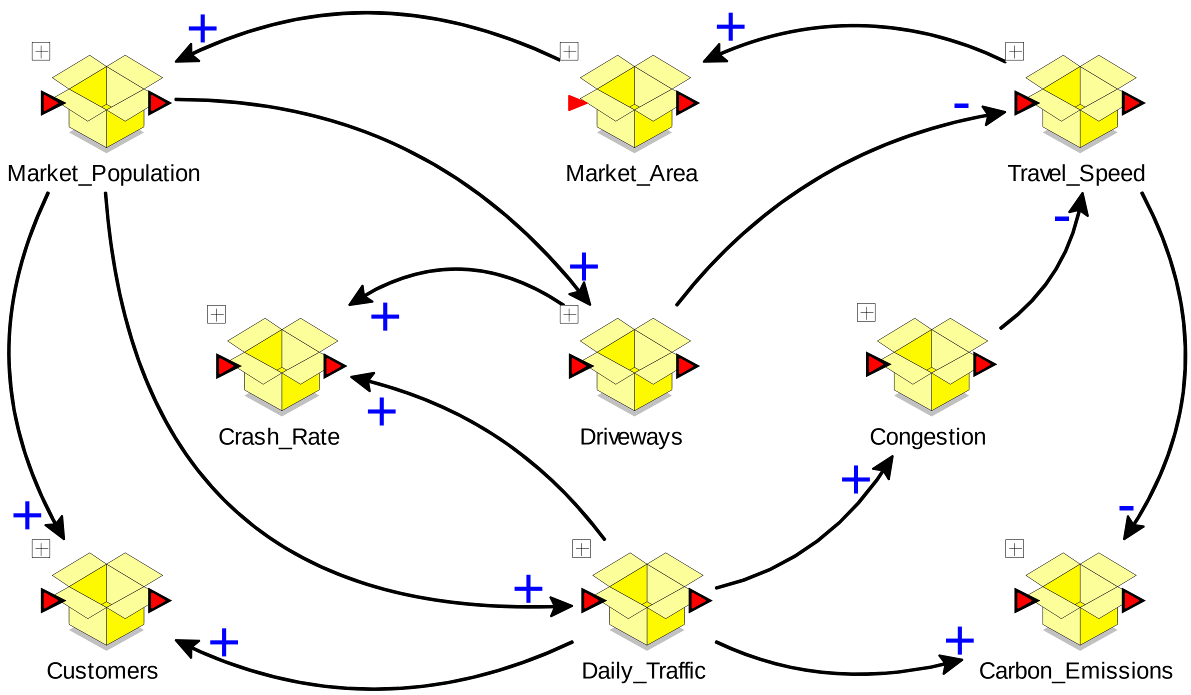
TABLE 3
Population Projections

	Commerce			Charleston			Cheyenne		
Year	0.5-mile radius	1.5-mile radius	3-mile radius	0.5-mile radius	1.5-mile radius	3-mile radius	0.5-mile radius	1.5-mile radius	3-mile radius
2009	63,278	190,573	387,993	89,768	209,001	461,565	71,226	153,552	378,929
2010	67,232	199,695	406,021	91,052	212,084	469,733	72,666	157,437	390,271
2011	70,006	206,624	421,699	92,198	213,846	473,414	72,931	159,347	393,916
2012	72,780	213,552	437,377	93,344	215,607	477,095	73,195	161,256	397,561
2013	75,554	220,481	453,054	94,490	217,369	480,776	73,459	163,166	401,207
2015	81,103	234,338	484,410	96,781	220,892	488,137	73,988	166,985	408,498
2017	81,487	248,640	512,131	97,159	221,900	489,906	74,021	168,226	412,754
2020	82,062	270,093	553,713	97,725	223,411	492,559	74,070	170,088	419,138
2025	84,102	277,798	619,001	97,888	223,930	493,531	76,093	173,696	423,283
2030	85,804	283,301	654,542	99,827	228,354	503,257	77,471	176,992	431,501

2.2.3.2 Model Relationships

All of the formulas driving the model are included in the relationships container. The sub-containers, as shown in Figure 10, help to organize the model and visually display its structure, similar to the causal loop diagram. Each sub-container includes individual variables, or elements, with mathematical equations describing its value in relationship to other elements in the model.

FIGURE 10
Relationships Container Structure



The full equations and diagrams for carbon emissions, crash rate, and travel speed are described below in detail, followed by summaries of the other sub-containers. The carbon emissions sub-container, shown in Figure 11, includes 10 elements. The formulas used to calculate the carbon emitted by all vehicles traveling a segment of roadway over a given period of time are shown in Table 4. The crash rate and travel speed sub-containers are shown in Figures 12 and 13, with the formulas used to calculate each in Tables 5 and 6.

FIGURE 11
Carbon Emissions Relationship Diagram

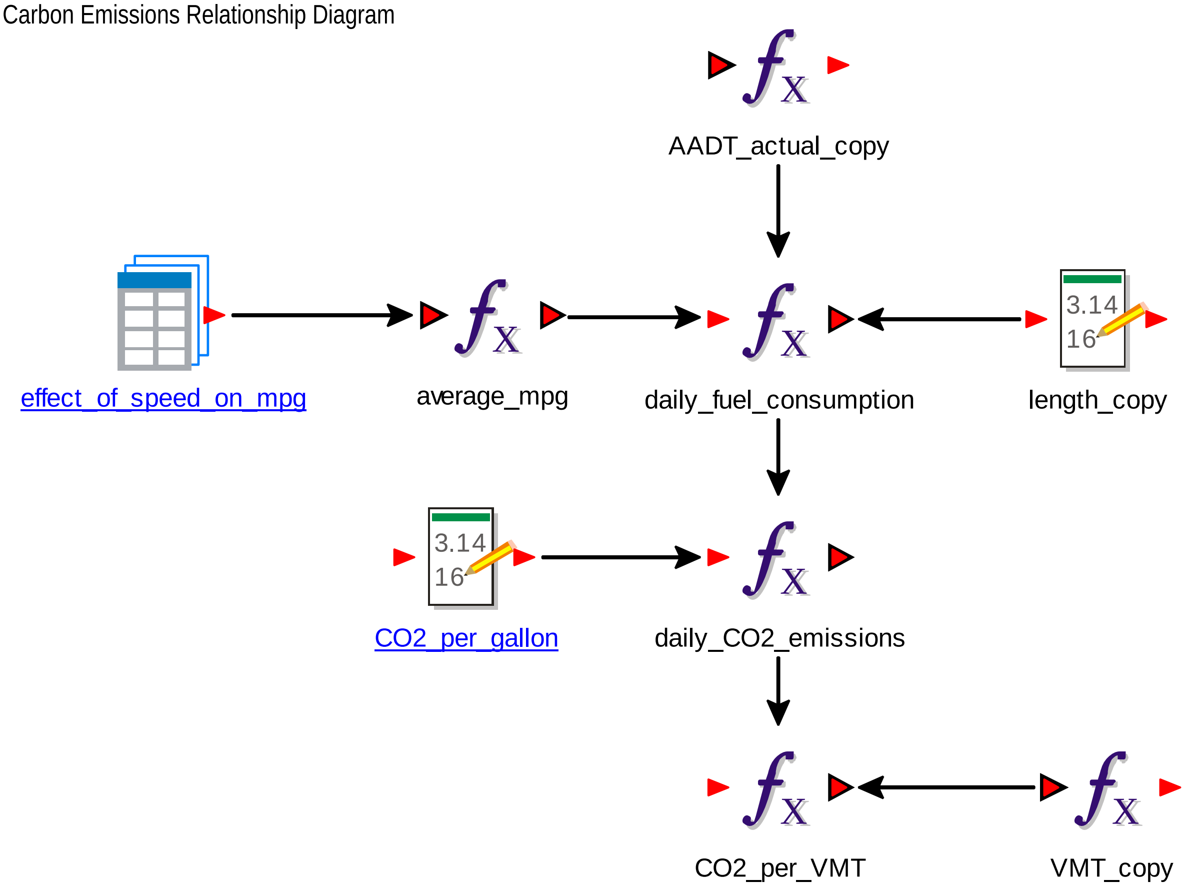


TABLE 4
Carbon Emissions Formulas

Element	Formula
daily_CO2_emissions	daily_fuel_consumption*CO2_per_gallon
CO2_per_gallon	8.8 kg/gal (EPA 2008)
daily_fuel_consumption	(length_copy/average_mpg)*AADT_actual_copy
length_copy	length of the segment (a copy from the Parameters container)
AADT_actual_copy	modeled average annual daily traffic (a copy from the Daily_Traffic container)
average_mpg	effect_of_speed_on_mpg*average_speed_actual
average_speed_actual	modeled average speed of traffic (from the Daily_Traffic container)
effect_of_speed_on_mpg	look-up table based on the information illustrated in Figure 6, Fuel Efficiency Curve
CO2_per_VMT	daily_CO2_emissions/VMT_copy
VMT_copy	modeled vehicle miles traveled (a copy from the Daily_Traffic container)

FIGURE 12
Crash Rate Relationship Diagram

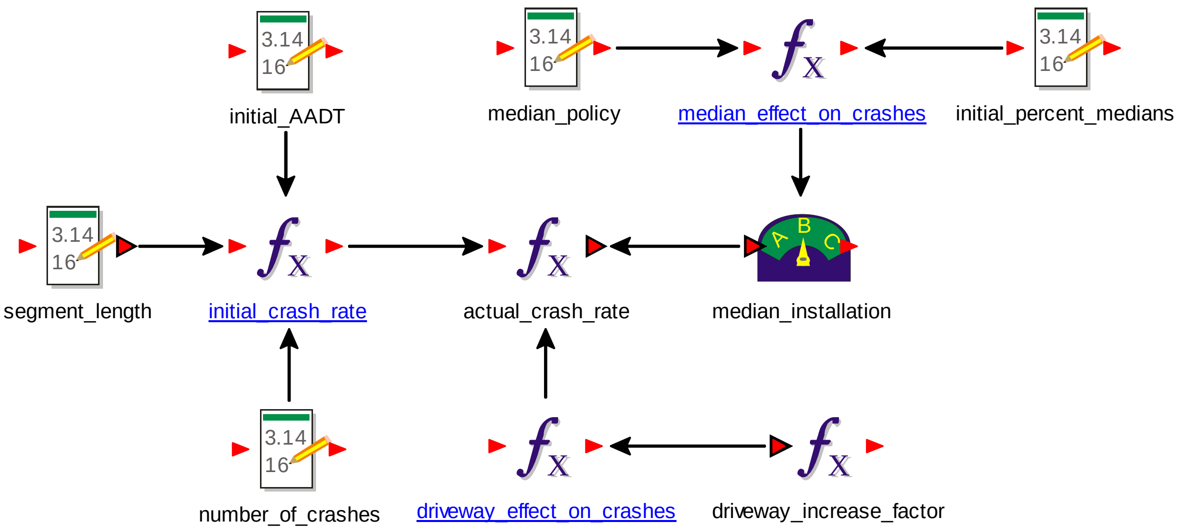


TABLE 5
Crash Rate Formulas

Element	Formula
initial_crash_rate	(number_of_crashes*1,000,000)/(segment_length*5*initial_AADT*365.25 day)
initial_AADT	39,122 1/day
segment_length	5.53809625096 miles
number_of_crashes	2,359 (over a 5-year period)
actual_crash_rate	initial_crash_rate*driveway_effect_on_crashes*median_installation
driveway_effect_on_crashes	sqrt(driveway_increase_factor) (TRB 2003)
driveway_increase_factor	driveways_per_mile_actual/driveways_per_mile_2008 (from the Driveways sub-container)
median_installation	This is a switch, or if/then/else statement, that triggers the median_effect_on_crashes element according to the policy implementation year.
median_effect_on_crashes	1.0-0.3*(median_policy-initial_percent_medians) (TRB 2003; “The average crash rate on roadways with a nontraversable median is about 30% less than on those with a TWLTL.”)
median_policy	User defined
initial_percent_medians	25%

FIGURE 13
Travel Speed Relationship Diagram

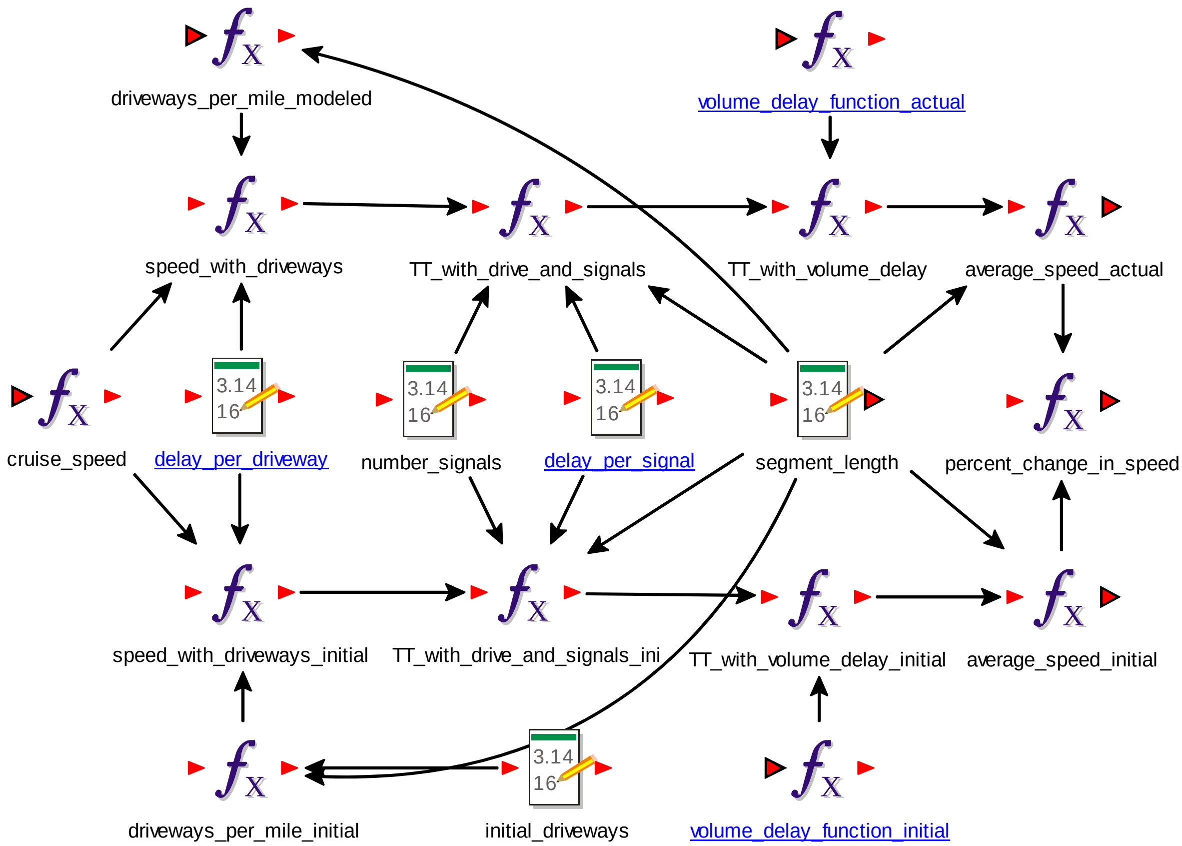


TABLE 6
Travel Speed Formulas

Elements (left to right, and top to bottom)	Formula
driveways_per_mile_modeled	total_driveways/segment_length
volume_delay_function_actual	1+0.15*V_over_C_actual^4 (Bureau of Public Roads 1964)
speed_with_driveways	cruise_speed-(driveways_per_mile_modeled*1 mi* delay_per_driveway)
TT_with_drive_and_signals	(segment_length/speed_with_driveways)+(delay_per_signal*number_signals)
TT_with_volume_delay	TT_with_drive_and_signals*volume_delay_function_actual
average_speed_actual	segment_length/TT_with_volume_delay
cruise_speed	speed_limit + 5 mph
delay_per_driveway	0.15 mph (TRB 2003)
number_signals	14
delay_per_signal	0.33 min (Parsons 2007; Formlua modified from Highway Capacity Manual. Calculation is based on: 40 mph posted speed, 140 second signal cycle length with 50% green time, and signal progression on a 2-way grid.)

TABLE 6
Travel Speed Formulas

Elements (left to right, and top to bottom)	Formula
segment_length	5.53809625096 mi
percent_change_in_speed	(average_speed_actual-average_speed_initial)/average_speed_initial
speed_with_driveways_initial	cruise_speed-(driveways_per_mile_initial*1 mi* delay_per_driveway)
TT_with_drive_and_signals_ini	(segment_length/speed_with_driveways_initial)+(delay_per_signal*number_signals)
TT_with_volume_delay_initial	TT_with_drive_and_signals_ini*volume_delay_function_initial
average_speed_initial	segment_length/TT_with_volume_delay_initial
driveways_per_mile_initial	initial_driveways/segment_length
initial_driveways	112
volume_delay_function_initial	1+0.15*V_over_C_initial^4 (Bureau of Public Roads 1964)

The **Market Population** is a function of the Market Area. As the market area grows or shrinks, it encompasses a larger or smaller portion of the population surrounding the roadway segment. Population projections were collected from a Clark County, Nevada geographic information system (GIS) database, in 0.5-, 1.5-, and 3-mile radii around each segment, to the year 2030, as shown earlier in Table 3.

The **Market Area** assumes a starting radius of 1.5 miles around the segment. As the as average speed at which vehicles travel through the segment decreases, due to poor operations and congestion, the market area decreases. This is described in section 3.1.4, and shown in Figure 8, Effects of Travel Time on Market Area.

Driveways are assumed to change in proportion to the population. This reflects the likelihood that as the population increases in the area, their will be an increased demand for services. More businesses will open, and as a result, more curb cuts, or driveways, will be created.

Congestion is a simple calculation of the volume of vehicles using the segment divided by its capacity. The capacity is assumed not to change, however volume does change with the population.

Daily Traffic is the average annual daily traffic (AADT), which changes in proportion with the population. In complex traffic models, AADT is a function of population, origin and destination trips, and many other factors. To create a generic formula applicable to any roadway segment, only population was used in this model.

Customers grow in direct proportion to the market population. Improvements in access management increase the travel speed, which increases the market area and population, increasing the number of customers. To date, studies have not been able to quantify the number of customers deterred from visiting a business because of reduced access, so assumptions are used in this model. Studies have shown that businesses that rely on drive-by customers are impacted the most. Therefore, the model accepts user-defined input to the current number of daily customers, the percentage of those customers that are drive-by customers, and the percentage of total customers that are assumed to be lost as a result of installing medians and consolidating driveways. The model outputs the number of customers based on these assumptions. The percent of customers lost due to access management is only the percent of drive-by customers. The model assumes that other customers intend to visit that place of business and will find a way to gain access.

2.2.3.3 Access Management Policies

The policies tested in this model are driveway spacing and consolidation, median installation, and the year in which these policies are implemented. The TRB published guidelines for access spacing on principle and minor arterials, shown in Table 7 (TRB 2003).

The average arterial in the Las Vegas Valley has 20 driveways per mile, on both sides of the road, which equates to 10 driveways per mile in each direction, for an average spacing of 528 feet. Because opposition to installing medians is far less than the opposition to consolidating driveways, median installation will always be considered and implemented first. For this reason, the likelihood of having a principal arterial with full median openings (no median) is very low and the need for 2640-foot spacing not necessary. Based on this information, the spacing options considered in this study are 330-, 660-, and 1320-feet.

TABLE 7
Guidelines for Access Spacing (ft) on Suburban Roads (Layton 1998, TRB 2003)

Functional Classification of Roadway	Full Median Opening	Closed Median (Right In/Out Only)	Directional Median Opening (left turns and U-turns)
Principal Arterial	2640	1320	1320
Minor Arterial	1320	330	660

There are two options for access spacing built in to this model. The first considers access spacing as a policy that only applies to new development, after the policy is implemented, and would not affect existing development. The second policy in the model would consolidate existing driveways to meet the revised spacing requirements. In each case, the year these policies are implemented is input into the model.

The model assumes that all medians installed will be closed, and only allow right-in and right-out movements. The model input for this policy lever is the percent of the segment with medians, to a maximum of 100% (openings at signalized intersections are assumed).

The other levers relate to the customer assumptions explained at the end of section 3.3.2. These levers, or inputs, allow the user to test various customer loss assumptions. Even the worse-case assumptions may not behave as poorly as expected, due to the positive growth pressures that accompany good access management.

2.2.4 Model Validation

Model validation was an iterative process conducted throughout development of the Cheyenne model—the model I later cloned to create models of Charleston and Commerce. As each new sub-container was added to the model, the model was tested and results checked against expected behavior. Figure 14 is a copy of the reference mode, or expected behavior, for carbon emissions in the absence of access management. Figure 15 is the actual model output. The trend is roughly the same.

Customer growth in the absence of access management is shown in Figure 16, the reference mode, and Figure 17, the model output. The model output graph includes two trend lines: actual and normal. The normal trend line assumes that customers grow directly proportional to the projected population growth. The actual trend line assumes that customers grow proportional to the modeled population growth, which is shrinking with the market area as a result of poor access management. So while the modeled business is not losing customers because of poor access management, as the reference mode suggests, customer growth is nevertheless slower than what would otherwise have been projected.

Other selected outputs are shown in Figures 18 – 21: market population, daily traffic, average travel speed, and the number of driveways per mile. The behavior of each matches the expected trend.

FIGURE 14
Reference Mode: Carbon Emissions in the Absence of Access Management

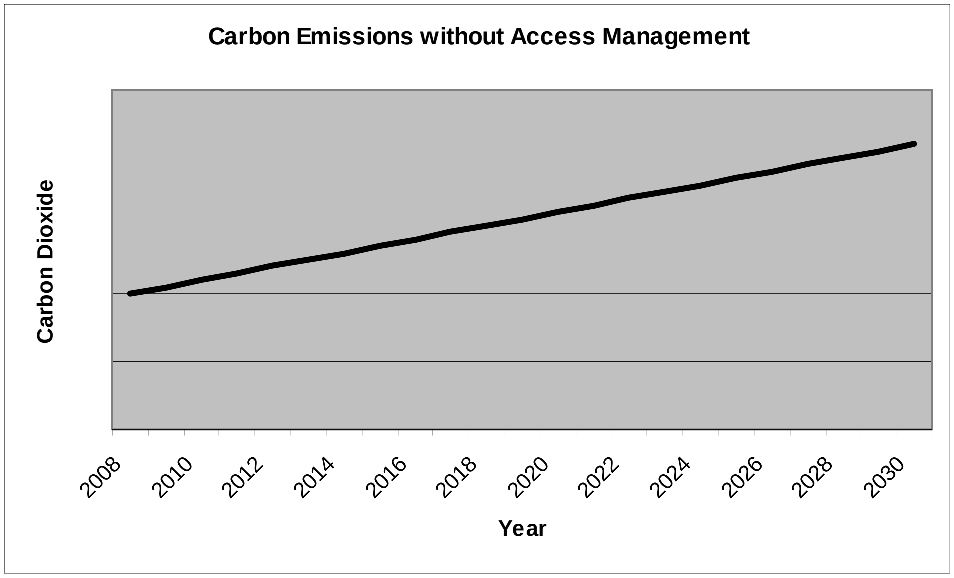


FIGURE 15
Model Output: Carbon Emissions in the Absence of Access Management

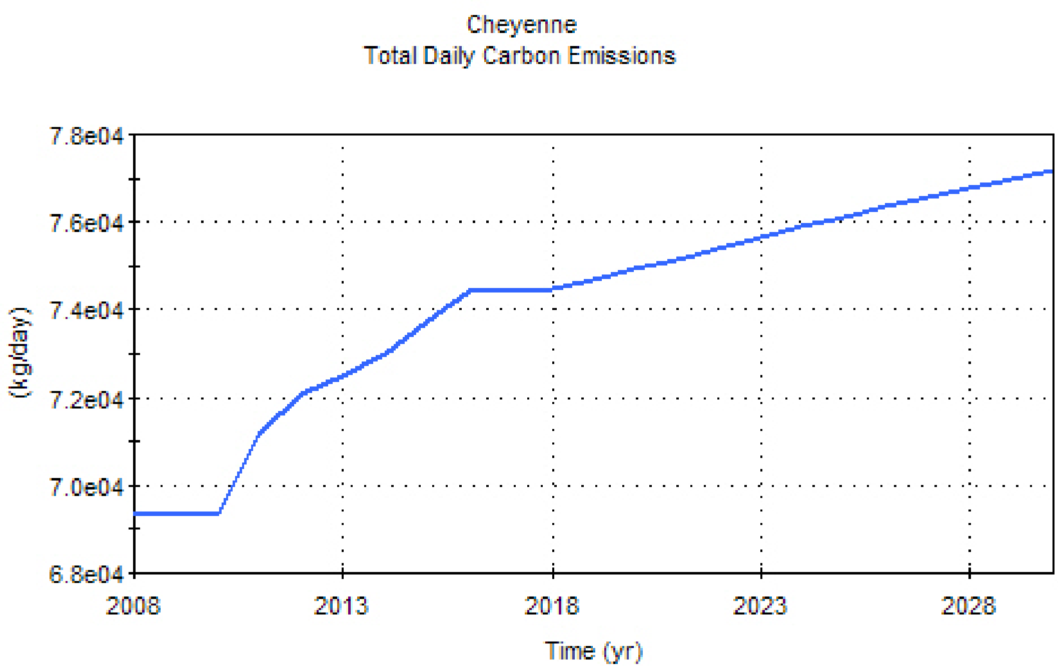


FIGURE 16
Reference Mode: Number of Customers resulting from Poor Access Management

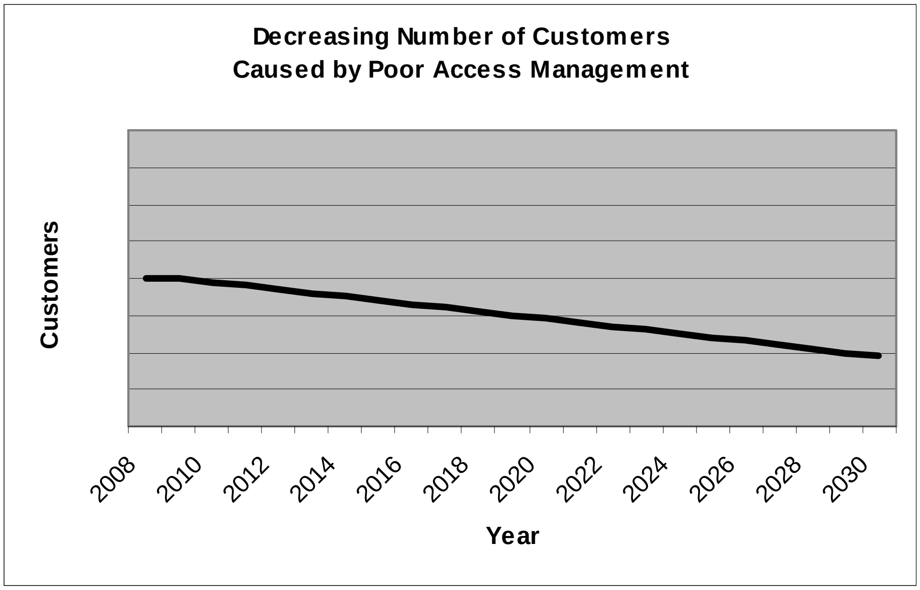


FIGURE 17
Model Output: Number of Customers resulting from Poor Access Management

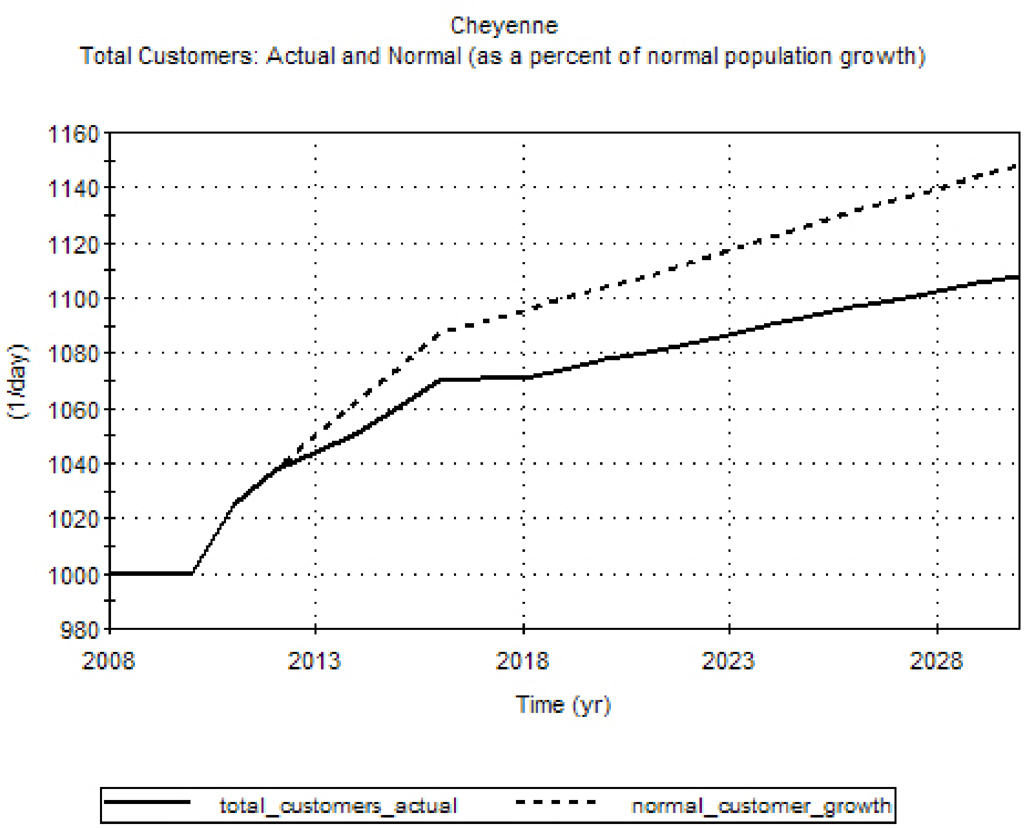


FIGURE 18
Market Population

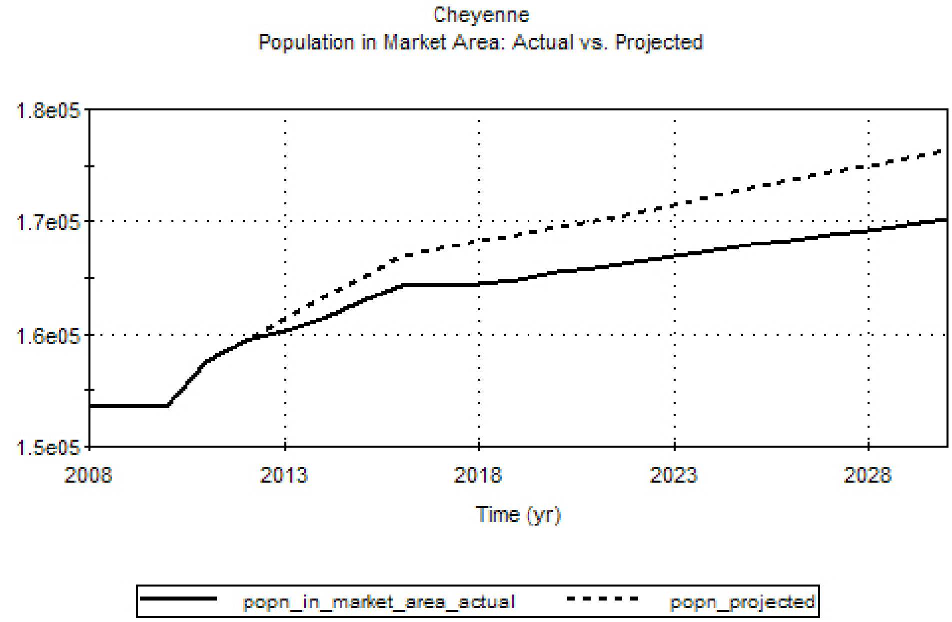


FIGURE 19
Daily Traffic

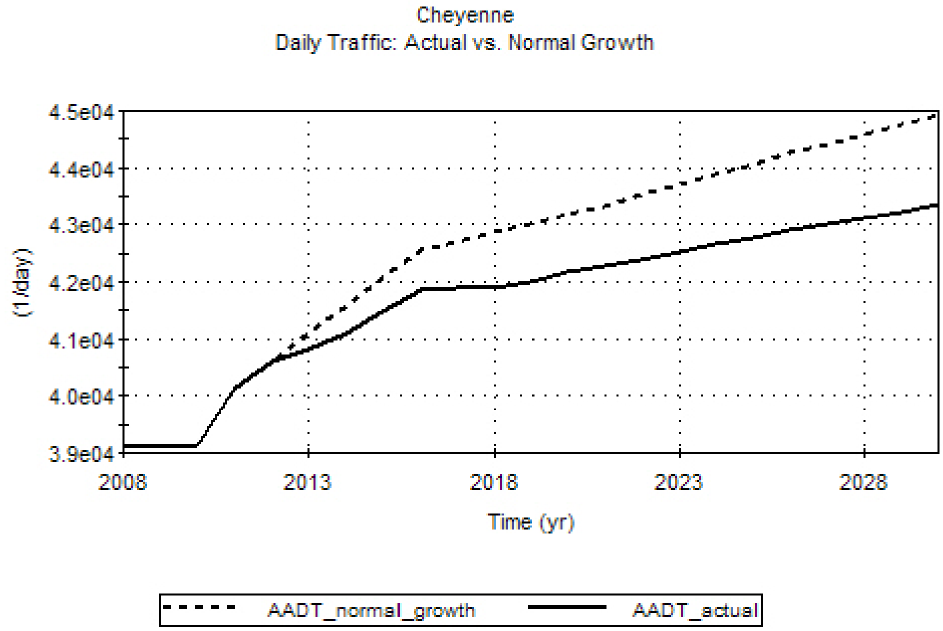


FIGURE 20
Average Travel Speed

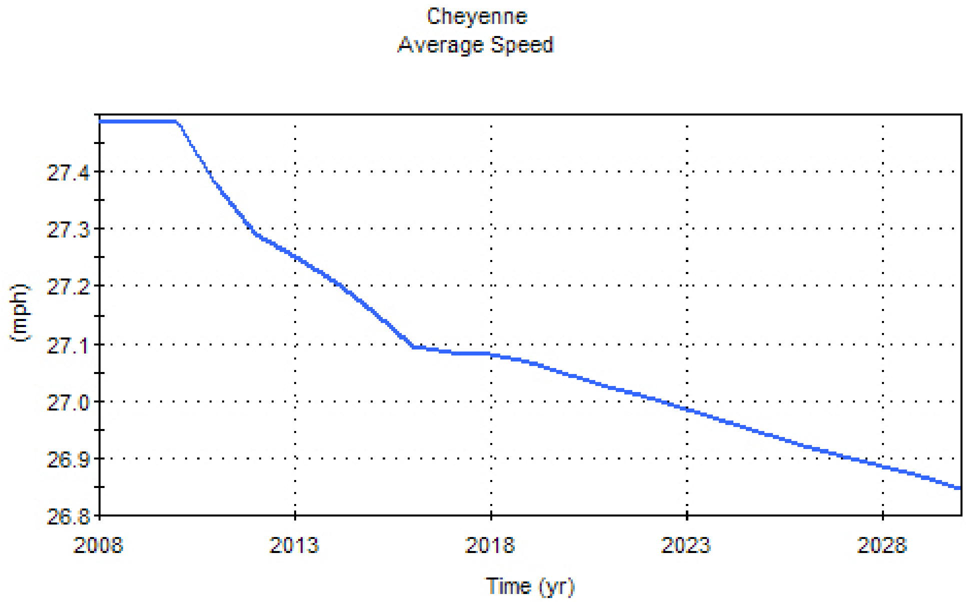
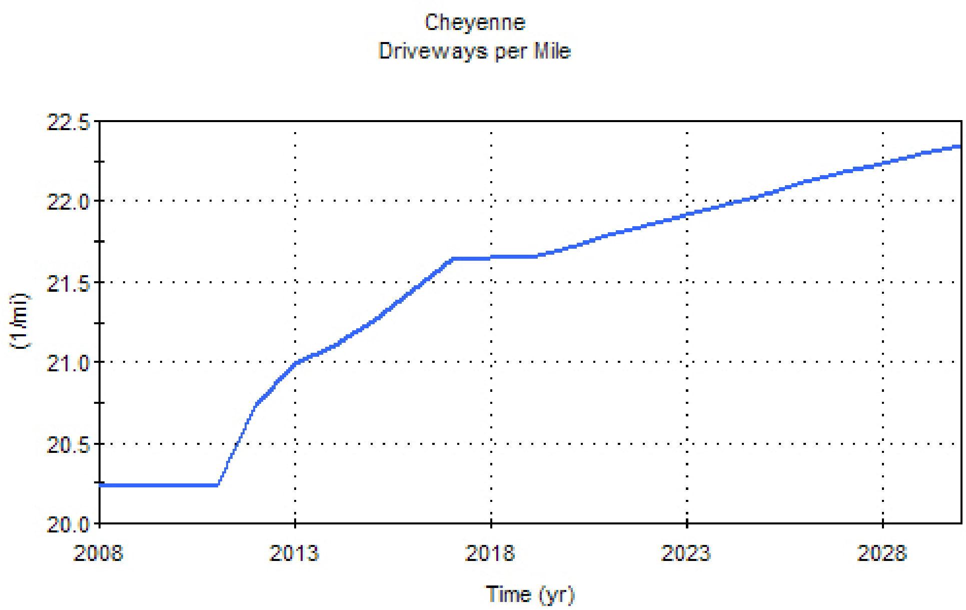


FIGURE 21
Number of Driveways per Mile



3. Model Results and Policy Evaluation

I tested and evaluated multiple combinations of policies and assumptions. This section includes the results of the policies I tested, the assumptions I made regarding customers, and some interesting and unexpected discoveries.

3.1 Results of Policy Tests

Several values for each policy were tested and evaluated. The model dashboard (Figures 22 – 24) shows the model outputs on the right which are associated with the policy inputs on the left. Policy inputs for driveway spacing were tested at 330, 660, and 1320 feet spacing, shown in Figure 22. There are minor changes in outputs from 330 feet spacing to 660 feet, however the results don't change beyond 660 feet. Driveways on Cheyenne are currently spaced about 530 feet apart. Establishing a future policy to limit the number of driveways beyond what is already in-place, has no effect unless we eliminate some of the driveways first. A more aggressive spacing policy, without consolidating some of the current driveways, will only have the effect of prohibiting the addition of more driveways—a policy that may not be practical.

Consolidating driveways, in the absence of a driveway spacing policy, will only reduce the number of driveways for a short period of time, until new development replaces them. Therefore, to test the policy of consolidating driveways, I set the driveway spacing value high enough so that it would not counteract the consolidation policy. The results of 30%, 60%, and 90% driveway consolidation are shown in Figure 23. While modest changes are observed as we progressively consolidate more driveways, eliminating 90% of the driveways on a roadway segment is not practical.

FIGURE 22
Results of Driveway Spacing Policy Tests

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	330
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	0
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	0
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	170151
Market Area:	2.875 mi
Daily Traffic:	43351.1 1/day
Volume/Capacity:	0.798
Average Speed:	26.85 mph
Driveways per Mile:	22.35 1/mi
Crash Rate:	6.74e6 1/milmi
Customers:	1108 1/day
Average MPG:	27.37 mpg
Daily Fuel Consumption:	8771.9 gal/day
Daily Carbon Emissions:	77192.9 kg/day
Carbon Emissions per VMT:	0.3215 kg/mi

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	660
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	0
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	0
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	170941
Market Area:	2.891 mi
Daily Traffic:	43552.3 1/day
Volume/Capacity:	0.802
Average Speed:	26.93 mph
Driveways per Mile:	20.22 1/mi
Crash Rate:	6.41e6 1/milmi
Customers:	1113 1/day
Average MPG:	27.39 mpg
Daily Fuel Consumption:	8807.4 gal/day
Daily Carbon Emissions:	77505.5 kg/day
Carbon Emissions per VMT:	0.3213 kg/mi

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	1320
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	0
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	0
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	170941
Market Area:	2.891 mi
Daily Traffic:	43552.3 1/day
Volume/Capacity:	0.802
Average Speed:	26.93 mph
Driveways per Mile:	20.22 1/mi
Crash Rate:	6.41e6 1/milmi
Customers:	1113 1/day
Average MPG:	27.39 mpg
Daily Fuel Consumption:	8807.4 gal/day
Daily Carbon Emissions:	77505.5 kg/day
Carbon Emissions per VMT:	0.3213 kg/mi

FIGURE 23
Results of Driveway Consolidation Policy Tests

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	1320
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	30
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	0
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	173238
Market Area:	2.938 mi
Daily Traffic:	44137.6 1/day
Volume/Capacity:	0.812
Average Speed:	27.15 mph
Driveways per Mile:	14.16 1/mi
Crash Rate:	5.37e6 1/milmi
Customers:	1128 1/day
Average MPG:	27.43 mpg
Daily Fuel Consumption:	8911.4 gal/day
Daily Carbon Emissions:	78420 kg/day
Carbon Emissions per VMT:	0.3208 kg/mi

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	1320
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	60
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	0
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	175457
Market Area:	2.982 mi
Daily Traffic:	44703 1/day
Volume/Capacity:	0.823
Average Speed:	27.37 mph
Driveways per Mile:	8.089 1/mi
Crash Rate:	4.06e6 1/milmi
Customers:	1143 1/day
Average MPG:	27.47 mpg
Daily Fuel Consumption:	9011.4 gal/day
Daily Carbon Emissions:	79300 kg/day
Carbon Emissions per VMT:	0.3203 kg/mi

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	1320
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	90
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	0
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	178086
Market Area:	3.021 mi
Daily Traffic:	45372.7 1/day
Volume/Capacity:	0.835
Average Speed:	27.55 mph
Driveways per Mile:	2.022 1/mi
Crash Rate:	2.03e6 1/milmi
Customers:	1160 1/day
Average MPG:	27.51 mpg
Daily Fuel Consumption:	9133.8 gal/day
Daily Carbon Emissions:	80377.4 kg/day
Carbon Emissions per VMT:	0.3199 kg/mi

The results of the policy to install medians are shown in Figure 24. Since 25% of Cheyenne is currently divided by a center median, the inputs tested were to install medians over 50%, 75%, and 100% of the roadway segment. All major and minor arterials in the Las Vegas Valley have either two-way-left-turn-lanes (TWLTL) or center medians. Converting a TWLTL to a nontraversable median has minimal operational benefits—so I did not include it. As shown in Figure 24, medians only affect safety.

3.2 Results of Customer Assumptions

Only drive-by customers can by lost due to median installation and driveway consolidation. The assumption I built in to the model is that other customers planned to visit the store and will be undeterred by the presence of medians or a reduced number of driveways. Setting any of the customer inputs—% Drive-by Customers, % Lost by Median Install, or % Lost by Driveway Consolidation—to zero will have no impact on the total number of customers. At the other extreme, if we assume that 100% of drive-by customers will be lost following installation of medians and consolidation of driveways, and that 100% of customers are drive-by customers; and we input the maximum values for the access management policies—we indeed lose every one of our customers. I tested several different assumptions regarding how customers might react to changes in access, shown in Table 8. This shows that a business could expect to pick-up a few more customers as a result of better access control, however, they could lose some due to the inconvenience of reduced access.

FIGURE 24
Results of Median Installation Policy Tests

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	1
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	0
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	50
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	170151
Market Area:	2.875 mi
Daily Traffic:	43351.1 1/day
Volume/Capacity:	0.798
Average Speed:	26.85 mph
Driveways per Mile:	22.35 1/mi
Crash Rate:	5.8e6 1/milmi
Customers:	1108 1/day
Average MPG:	27.37 mpg
Daily Fuel Consumption:	8771.9 gal/day
Daily Carbon Emissions:	77192.9 kg/day
Carbon Emissions per VMT:	0.3215 kg/mi

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	1
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	0
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	75
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	170151
Market Area:	2.875 mi
Daily Traffic:	43351.1 1/day
Volume/Capacity:	0.798
Average Speed:	26.85 mph
Driveways per Mile:	22.35 1/mi
Crash Rate:	5.33e6 1/milmi
Customers:	1108 1/day
Average MPG:	27.37 mpg
Daily Fuel Consumption:	8771.9 gal/day
Daily Carbon Emissions:	77192.9 kg/day
Carbon Emissions per VMT:	0.3215 kg/mi

Cheyenne East (Segment 08)

Policy Inputs

Driveway spacing (330, 660 or 1320 ft.)	1
Driveway Spacing Implementation Year	2008
Driveway Consolidation (Percent)	0
Driveway Consolidation Implementation Year	2008
Median Installation (Percent)	100
Median Installation Implementation Year	2008
Total Customers	1000
% Driveby Customers	20
% Lost by Median Install	0
% Lost by Driveway Consolidation	0

Year 2030 Final Values

Market Population:	170151
Market Area:	2.875 mi
Daily Traffic:	43351.1 1/day
Volume/Capacity:	0.798
Average Speed:	26.85 mph
Driveways per Mile:	22.35 1/mi
Crash Rate:	4.86e6 1/milmi
Customers:	1108 1/day
Average MPG:	27.37 mpg
Daily Fuel Consumption:	8771.9 gal/day
Daily Carbon Emissions:	77192.9 kg/day
Carbon Emissions per VMT:	0.3215 kg/mi

TABLE 8
Output from Customer Assumptions

Policy / Inputs	No Access Mgmt	Recom-mended AM	Recom-mended AM	Recom-mended AM	Recom-mended AM	Recom-mended AM
Driveway Spacing (ft)	1	1320	1320	1320	1320	1320
Driveway Consolidation (%)	0	30	30	30	30	30
Median Installation (%)	0	100	100	100	100	100
Customer / Inputs	**No Customer Loss**	**No Customer Loss**	**Best Case**	**Average**	**Below Average**	**Gas Station**
% Drive-by Customers	0	0	10	20	30	60
% Lost by Median Install	0	0	20	50	50	50
% Lost by Driveway Consolidation	0	0	20	50	50	50
Total Customers in year 2030	**1108**	**1128**	**1099**	**982**	**908**	**688**
% Change from No Access Mgmt	**0.00%**	**1.81%**	**-0.81%**	**-11.37%**	**-18.05%**	**-37.91%**

3.3 Other Observed Results

After testing a number of combinations of policy inputs and customer assumptions, I did not notice dramatic changes in the model outputs as a result of controlling access, with the exception of safety improvements. So I began looking for, and testing, other variables in the system that might have a significant impact on operations. I discovered that traffic signals reduce the average travel speed more than any other variable. By manipulating the number of traffic signals from 14 to 11, about a 20% reduction, the average travel speed increased by 9%. Larger percent changes in driveways and medians result in much smaller changes in speed.

3.4 Combined Policy Results and Evaluation

I selected a set of reasonable policy inputs that resulted in the greatest improvements, and ran these policies for the three segment models: Cheyenne, Charleston, and Commerce. Results from these three models were compared and averaged, shown in Table 9. There are only modest improvements to most of the outputs when the access management policies tested for in this model are implemented. The one exception is safety. Access management significantly reduces the crash rate—by an average of 43%. This supports much of the literature on access management which stresses improved safety as the primary benefit of access control.

A more aggressive access management program than the policies tested in this model does not result in significant improvements, other than in safety. For instance, eliminating 80% of the driveways on the Charleston segment only results in an average speed of 24.5 mph—a 0.5 mph increase over a policy to consolidate 30% of the driveways. (However, the crash rate would drop nearly in half, to 3.2). Such a policy would require a significant amount of political capital, right-of-way purchases, and engineering to consolidate that many driveways or relocate them to adjacent side streets.

Projected population growth in the Las Vegas Valley will continue to drive up traffic volumes and congestion. Modeling that growth was important to show that by not controlling access, congestion and the environment will deteriorate. However it also makes it difficult to see the benefits of access management because they both appear to deteriorate even when access management is applied. So while increases in population result in increases in congestion and pollution, even with better access control, but they increase at a slower rate.

TABLE 9
Comparative Results from the Cheyenne, Charleston, and Commerce Models

	Population	Market Area	Average Volume	Average V/C	Average Speed	Driveways / Mile	Crash Rate	Customers	Average MPG	Fuel Consumption	Carbon Emissions	Emissions per VMT
Segment	no.	miles	AADT	ratio	mph	no./mi	no.	no.	mpg	gal/day	kg/day	kg/mile
Cheyenne 2008	153,552	3.000	39,122	0.72	27.49	20.22	5.96	1,000	27.50	7,879	69,338	0.3200
Cheyenne 2030 No AM	170,151	2.875	43,351	0.80	26.85	22.35	6.74	1,108	27.37	8,772	77,193	0.3215
Cheyenne 2030 with AM	173,238	2.938	44,138	0.81	27.15	14.16	3.87	1,128	27.43	8,911	78,420	0.3208
% change 2008 – 2030 No AM	10.81%	-4.17%	10.81%	10.91%	-2.33%	10.51%	13.09%	10.80%	-0.47%	11.33%	11.33%	0.47%
% change 2030 AM – 2030 No AM	1.81%	2.19%	1.82%	1.75%	1.12%	-36.64%	-42.58%	1.81%	0.22%	1.58%	1.59%	-0.22%
Charleston 2008	209,001	3.000	48,900	0.76	23.87	40.15	8.49	1,000	26.77	12,418	109,278	0.3287
Charleston 2030 No AM	222,802	2.927	52,129	0.82	23.54	42.48	9.70	1,066	26.71	13,271	116,785	0.3295
Charleston 2030 with AM	229,988	3.028	53,810	0.84	23.97	28.11	5.98	1,100	26.79	13,655	120,166	0.3284
% change 2008 – 2030 No AM	6.60%	-2.43%	6.60%	6.66%	-1.38%	5.80%	14.25%	6.60%	-0.22%	6.87%	6.87%	0.24%
% change 2030 AM – 2030 No AM	3.23%	3.45%	3.22%	3.19%	1.83%	-33.83%	-38.35%	3.19%	0.30%	2.89%	2.90%	-0.33%
Commerce 2008	190,573	3.000	10,070	0.49	32.01	9.9	4.12	1,000	28.40	2,258	19,870	0.3098
Commerce 2030 No AM	263,249	2.807	13,910	0.67	30.89	13.62	4.83	1,381	28.18	3,144	27,665	0.3123
Commerce 2030 with AM	273,909	2.916	14,474	0.70	31.50	6.93	2.46	1,437	28.30	3,257	28,661	0.3109
% change 2008 – 2030 No AM	38.14%	-6.43%	38.13%	38.08%	-3.50%	37.68%	17.23%	38.10%	-0.77%	39.24%	39.23%	0.81%
% change 2030 AM – 2030 No AM	4.05%	3.88%	4.05%	4.03%	1.97%	-49.16%	-49.07%	4.06%	0.43%	3.59%	3.60%	-0.45%
Average % change 2030 AM – 2030 No AM	3.03%	3.18%	3.03%	2.99%	1.64%	-39.88%	-43.33%	3.02%	0.31%	2.69%	2.69%	-0.33%

4. Discussion

The policies tested and recommended are reasonable: access spacing of 1320 feet, 30% driveway consolidation, and 100% median installation. Access management policy recommendations are included in the RTC study that I am managing for CH2M HILL. In a working group meeting with transportation engineers and planners from the RTC, Clark County and each of the cities in the Las Vegas Valley, everyone agreed that the RTC needs to tighten design standards for major arterials with respect to medians. At present, major arterials can be constructed with either center medians or TWLTLs. The working group recommended omitting the option for TWLTLs when constructing a new major arterial. Nearly every arterial improvement project in the Las Vegas Valley includes installing medians throughout the project limits. Drivers are accustomed to closed medians on most principle arterials, and will likely not oppose the addition of more.

Consolidating 30% of existing driveways can often be accomplished by merely closing one or more driveways to parcels that have several. Limiting driveways to only 4 per mile, per direction (spacing them 1320 feet apart) is somewhat more challenging. The key is to implement this spacing policy before the roadway segment is developed.

Throughout development of the RTC study I had opportunities to discuss other access management techniques and policies with several traffic engineers. Most seemed to think that eliminating traffic signals would be a very difficult task—from a political, planning, and engineering standpoint. For that reason, I did not start this study with the intention of considering a policy to limit the number of signals. However, after observing the dramatic effect that each signal can have on the flow of traffic and the average travel time, I believe we need to look closer at policies to limit their use. Of course signals are critical for coordinating the operations of the entire transportation grid, and cannot be considered in a vacuum—on just one segment at a time. But signals at locations that do not serve the grid, such as in front of a major development, should be limited. Access to that development should be provided, where possible, from a side street—a minor arterial or collector—whose purpose it is to collect that type of traffic and feed it into the major arterial at limited and strategic locations.

The model shows that the total amount of carbon emitted from vehicles driving the segment increases, even with better access management. This is due, in part, because access management increases the size of the market area and population, and therefore draws more vehicles to that segment of roadway. In reality, these vehicles come from somewhere else—a nearby roadway segment—and do not increase the overall pollution in a metropolitan area. Therefore, the more important value to consider is the amount of carbon emitted per vehicle mile traveled—which the model shows decreasing with better access control. Emissions per VMT only drop 0.25%, however that equates to a 185 kg/day reduction in carbon emissions along the segment, and over 5,000 metric tons per year from the entire Las Vegas Valley, from roadway segments with similar characteristics.

Implementing these policies appears to result in minor improvements to the environment. Therefore, I believe my hypothesis is correct, that controlling access by limiting the number of driveways and installing center medians will reduce the total amount of daily carbon emitted from vehicles using a given roadway. My second hypothesis is inconclusive—that limiting the number of driveways and installing center medians will have no impact to local businesses that do not rely heavily on drive-by traffic. In order to accurately model the business impacts, we need better data on the percent of customers that would be deterred from visiting a business because of reduced access.

5. References

Bureau of Public Roads. 1964. *Traffic Assignment Manual*. Washington D.C.: U.S. Department of Commerce, Urban Planning Division.

CH2M HILL. 2008. *Las Vegas Valley Arterial Development Study*. Las Vegas: Prepared for the Regional Transportation Commission of Southern Nevada.

Diamond, B. 2008. *Simulation Overview*. Accessed May 1, 2008, from http://www.extendsim.com/sols_simoverview.html.

Eisele W. and W. Frawley. 1999. Research Report 3904-3: A Methodology for Determining Economic Impacts of Raised Medians: Data Analysis on Additional Case Studies. College Station: Texas Transportation Institute. Accessed 1/16/2008 from http://tti.tamu.edu/documents/3904-3.pdf.

Frey, H., N. Rouphail, A. Unal, and J. Colyar. 2001. *Emissions Reduction Through Better Traffic Management: An Empirical Evaluation Based Upon On-Road Measurements*. Raleigh: Center for Transportation and the Environment, Department of Civil Engineering, North Carolina State University.

Gluck, J., H. Levinson, and V. Stover. 1999. *NCHRP Report 420: Impacts of Access Management Techniques.* Washington, D.C.: National Cooperative Highway Research Program.

GoldSim. 2008. GoldSim. Accessed 11/21/08 from: http://www.goldsim.com

isee systems. 2008. *isee systems: the world leader in Systems Thinking Software*. Accessed 11/21/08 from: http://www.iseesystems.com

Layton, R. 1998. *Decision Paper 5B: Access Management Spacing Standards*. Salem: Oregon Department of Transportation.

Levinson, H. 2000. Access Spacing and Accidents: A Conceptual Analysis. Transportation Research Circular E-C019. Washington: Transportation Research Board, National Research Council.

Maze, T. 1997. *Access Management Awareness Program, Phase II Report*. Ames: Center for Transportation Research and Education, Iowa State University. Accessed 2/9/2008 from http://www.ctre.iastate.edu/research/access/index.htm#reports.

Parsons. 2007. *Free-Flow Speed Processing*. Las Vegas: Prepared for the Regional Transportation Commission of Southern Nevada.

Powersim. 2008. *Powersim*. Accessed 11/21/08 from: http://www.powersim.com

Reilly, W., D. Harwood, J. Schoen, R. Kuehl, K. Bauer, and A. St. John. 1989. *Final Report, NCHRP Project 3-33: Capacity and Level-of-Service Procedures for Multilane Rural and Suburban Highways.* Washington, D.C.: National Cooperative Highway Research Program.

Sterman, J. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: McGraw-Hill.

Stover, V., and F. Koepke. 1988. Transportation and Land Development. Washington, D.C.: Institute of Transportation Engineers.

System Dynamics Society. 2008. What is System Dynamics? Accessed 5/5/2008 from http://www.systemdynamics.org.

Transportation Research Board. 2003. Access Management Manual. Washington: Transportation Research Board.

Transportation Research Board. 2007. Determining the Economic Value of Roadway Access Management. Accessed 2/9/2008 from http://rns.trb.org/dproject.asp?n=13779.

Transportation Research Board. 2008. Update of the TRB Access Management Manual. Accessed 2/9/2008 from http://rns.trb.org/dproject.asp?n=13789.

U.S. Army Corps of Engineers. 2008. *The Hydrologic Engineering Center*. Accessed April 30, 2008, from http://www.hec.usace.army.mil.

US Department of Energy and US Environmental Protection Agency. 2008. *Gas Mileage Tips: Driving More Efficiently*. Accessed 9/13/08 from: http://www.fueleconomy.gov/feg/driveHabits.shtml.

US Environmental Protection Agency. 2008. *Greenhouse Gas Equivalencies Calculator*. Accessed 9/13/08 from: http://www.epa.gov/cleanenergy/energy-resources/calculator.html

Vensim. 2008. *Vensim from Ventana Systems, Inc*. Accessed 11/21/08 from: http://www.vensim.com

West, B., R. McGill, J. Hodgson, S. Sluder, and D. Smith. 1999. Development and Verification of Light-Duty Modal Emissions and Fuel Consumption Values for Traffic Models. Oak Ridge: Oak Ridge National Laboratory.