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Comparison of various methods to compute access density and proposing a weighted methodology

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Comparison of Various Methods to Compute Access Density and Proposing a Weighted Methodology

By

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DEDICATION

I dedicate this work to the four pillars of my life: God, my parents, and my brother and my friends. Without you all my life would fall apart.

My parents Kishore and Chhaya who sent me to University of South Florida to pursue my Masters degree. They always told me to “reach for the stars.” I think I got my first one. Thanks for all the encouragement and inspiring my love for transportation.

My brother Rahul has always extended his support and invaluable guidance which motivates me to move ahead towards my career goals. Thank you very much Rahul Da.

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Last and most importantly I am thankful to my dearest friend God for my existence.
I might not know where life’s road will take me, but walking with You, my Friend has always given me strength.

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COMPARISON OF VARIOUS METHODS TO COMPUTE ACCESS DENSITY AND PROPOSING A WEIGHTED METHODOLOGY

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ABSTRACT

This study aims to compare three distinct methods used to compute access density and provide a comprehensive weighted methodology to enable standardization for research and application in the future. Access density is a widely used concept that calculates the number of access points within a given distance and has been extensively applied to studies related to crash modeling, operational impact and planning.

Methods used in past research show that access density is computed differently by different studies and all studies do not include all access points. The weighted methodology proposed takes into account all access points including driveways, intersections and median openings and categorizes them into geometric combinations. Each geometric combination have potential number of conflict points which include diverging, weaving, merging and crossing movements depending on the type of access point. Weights were assigned to each geometry type based on these conflict point ratio.

In conclusion the study identifies and compares methods previously used to compute access density and accordingly, recommends a weighted methodology that includes all access points which can be used as a standard, universal measure all access density related studies including but not limited to safety impacts, operational impacts and planning guidelines.

CHAPTER 1 INTRODUCTION

1.1 Background

Access management is defined by the access management manual [33] as the systematic control of location, spacing, design and operations of driveways, median openings, interchanges and street connections to a roadway. Number of access points per mile is represented by access density of the arterial and it potentially measures the performance and conveys the safety and operational impact of the roadway. As evident from the definition various access management techniques involve systematic location and spacing of the access points while dealing with fundamental traffic problems of increasing number of vehicular crashes, increased travel times and resultant increased fuel consumption and vehicular emissions.

Traditional approach to deal with congestion and poor level of service is to widen the existing lanes and increase roadway capacity; however these solutions are not always feasible due to limited land availability and huge capital investments required to purchase right of way for road widening. With time, any increased capacity follows the land use cycle and eventually results in reduced level of service and thus once again requiring new arterial improvements. Access management techniques break this cycle to achieve improved efficiency by effectively managing the existing access points and developing guidelines, policies, regulations and geometric design requirements to achieve benefits.

Broadly access points include all openings like driveways, intersections or median openings along the arterial; however many times they are divided into various terms as shown in figure 1 such as “signal density”, “driveway density”, “median density”, “intersection density”, “midblock density”, “private access density”, “public access density.”, etc. to study the individual impact of these points. Various crash prediction models which study safety impact and operating speed models which study operational impact use individual terms which are discussed in detail in chapter 2.

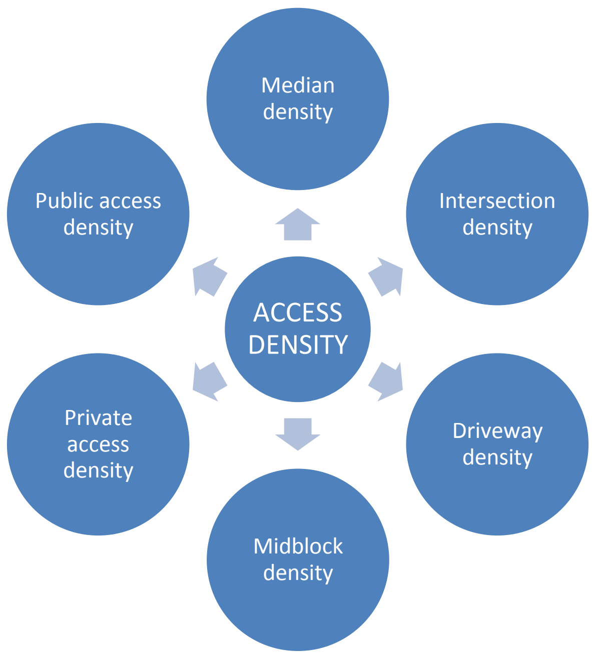


Figure 1: Access Density Related Terms

To find the frequency of usage of these terms in technical papers, the number of hits for these individual terms was obtained from an online search done in the reputed Transportation Records (TRR) of Transportation Research Board (TRB) database accessed in August 2009. Table 1 shows the results of number of hits.

Table 1: Number of Online Hits for Access Related Terms

No	Term	Number of hits in TRR (TRB)
1	Access Density	1039
2	Signal Density	767
3	Median Density	458
4	Driveway density	108

This shows that in technical papers access density term is very popularly used and signal density and median density are also consistently used. Despite the importance of individual terms there are many inconsistencies in defining the computational method of access density which is further discussed in 1.2.

1.2 Problem Statement

Access density is used to predict crashes, to study operational effects on travel times, delays, vehicle emissions and to develop planning guidelines and standards. Different studies include access points based on their research objectives and thus lack a consistent and comprehensive approach in computing the term. In order to accurately evaluate studies related to access density, a standardized universal method is required. There is a need to and compare the various methods and propose a weighted method that can be used as a standard methodology across all access density related research studies including but not limited to safety impacts, operational impacts and planning guidelines.

1.3 Proposed Study

This proposed study deals with studying the following aspects related to access density for urban arterial roadways:

1. Conducting a thorough literature review to study the existing methods of computing access density in crash prediction models and operational impact studies.
2. Capturing the difference in types of access points by giving those weights and defining a weighted computational approach which could be consistently used to compute access density.
3. Performing statistical tests to test the improvement of the proposed weighted methodology over the different existing methodologies.
4. Summarizing the steps to be followed for computing the proposed weighted methodology which could be easily used by researchers.

Crash rate of an arterial depends on many factors other than access density which are not being included in this study. This study will focus on arriving at a comprehensive methodology to compute access density.

1.4 Approach

The approach adopted for the proposed study consists of the following steps:

1. Conducting a detailed literature review to study the existing definitions and computational methods of defining access density.
2. Selecting an urban arterial whose crash data is available and which has a good number of access points to study safety impacts.
3. Using Google Earth 2009 to collect the access details.
4. Obtaining crash data for the selected roadway arterial
5. Use straight line diagrams for the selected roadway arterial to join access and crash data.

6. Classify the different access points in a detailed way to be useful in computing access density based on various definitions.
7. Assign weights to every access point to arrive at weighted access density.
8. Computing the crash rate for the selected arterial.
9. Correlating the crash rate and access density obtained from different definitions in previous studies and the proposed weighted access density.
10. Performing statistical tests to capture the improvement in correlation values obtained with the proposed definition.
11. Summarizing the findings in well defined steps which can be used to calculate weighted access density.

1.5 Brief Results

1. Three commonly used definitions of computing access density which were studied are found to be statistically the same.
2. The second approach of calculating weighted access density is proposed because it shows improved correlation with the crash rate and it is statistically different from the existing three computational methods of defining access density.
3. This study does not aim to provide a conclusive methodology; however it aims at providing a standard methodology that can be used across all access density related studies including but not limited to safety impacts, operational impacts and planning guidelines.

1.6 Outline of Thesis

Chapter 2 talks about various previous studies and their methods of computing access density. It also talks about the importance of access density term in safety and operational areas. Chapter 3.1 talks about the three identified methods of computing access density term and chapter 3.2 talks about the need for giving weights to the access points. Chapter 4 explains the study location chosen for the research and description of the access data collected from Google Earth and computation of crash rate for the selected urban arterial. Chapter 5 discussed the results based on the access data collected. It includes the three existing methods and the two approaches of weighted access density. Chapter 6 includes the statistical tests performed on the results obtained which are used to draw conclusions compiled in Chapter 7 followed by recommendations for researchers. This chapter also summarizes the steps that can be followed to arrive at weighted access density and states its advantages over other definitions.

CHAPTER 2 LITERATURE REVIEW

Literature review in this chapter consists of two parts. The first part covers the application of access density term in various crash prediction models. Much research has been done in this area and it is difficult to cover the whole body of literature. The second part of the literature is a review of previous studies related to operational impact of access management techniques. The methodology and framework will be further discussed in detail in Chapter 3.

2.1 Crash Modeling Related Research

Access density is a commonly used independent variable in various crash predicting models. There are various studies [1, 8, 10] which use access density as a significant independent variable to identify the relationship between safety (crash rates / crash frequency) and various roadway characteristics. Various access data collecting methods have been used in several studies which include using ESRI ArcGIS [4] and more specifically ArcGIS orthophotos [12], state photo logs [5,16], state video-log database [10] and state data collection documents, maps and road viewer program in addition to Google maps [13].

Many studies have found that as the density of access points increases, the accident rate also increases [1, 2] which is not a surprising finding [15] given that the more number of access points there are in a segment, the higher the number of conflicting movements. This trend holds true regardless of the median type [3] however inclusion of a particular type of median opening has an impact on crash rate [3, 11]. The before-after study done by (3) investigated the crash data and found reduction in crash rates after installation of raised median. Contradictory to this finding, it was observed that it is not necessary to detect significant differences in safety between urban highways with and without a median if the median has openings at intersections [10].

A lot of inconsistency has been observed in defining the term ‘access’ as used in models. It is found that various access points are excluded while computing access density in different studies. A study by [7)] defines access density as number of driveways (on both sides of the road) per mile. With an assumption that driveways include intersections, it can be seen that median openings are not considered in the density calculations. Study [10] defines access density as the number of access points per km and provides no details regarding the inclusion of all access points namely driveways, intersections and median openings. Study by [8] found that driveway density, un-signalized public street density and median type are significantly correlated with accident frequency. A study by [5] describes access as the number of driveways and minor intersections and further categorizes driveways based on land use including residential, office, retail and industrial. This definition excludes access points such as median openings and major intersections. Overall, these studies not only show inconsistencies in computing access density, but they also present a distinction between the terms ‘driveway’ and ‘intersection’ that hinders the purpose of such research. There is no mention of any criteria used to distinguish between driveways and minor intersections [5].

As noted by the American Association of State Highway and Transportation Officials (AASHTO) in their publication “Green Book" (1994, page 793), driveways create intersections with the street system. There is a need to clarify what stand we take in incorporating driveways while computing access density. We need to consider if access points should be differentiated as driveways and intersections or whether fundamentally both must be considered as intersections for the purpose of computing access density.

Based on the specific research objectives of different studies, terms related to access are defined differently [4, 6]. A study in a metropolitan area focused on commercial driveway density since they generate more trips compared to residential driveways [4, 12]. A study on the safety of curbs [6] included active un-signalized intersections and driveways larger than those built for a single family residential house. Study [9] focused on the effects of midblock access points and thus, used the term access density to represent access points in between intersections. In order for this term to include all midblock access points, median opening access points in between intersections should have been included as well. In studying the effects of median treatment and access for rural highways [20], crashes were grouped based on low access of less than 20 points; medium access within the 20-40 point range and high access with more than 40 points. From this study too, it can be observed that there is no mention of inclusion of median openings as access points. A significant contribution towards assigning weights based on the type of intersection (four-legged or T intersection) and presence of a traffic signal was found in only one study [10] which defined access density with driveway densities and public street intersections terms. Signalized intersections (four-legged or T intersection) were assigned an equivalent weight of two access points because of increased rear-end crashes at traffic signals. In the case of un-signalized four-legged intersections, the equivalent weight was maintained as two due to the presence of access points on both sides of the main arterial and a three way un-signalized intersection was considered as only one access point.

Each of these access points provide a gross measure of the relative amount of conflict opportunities [6] caused either by diverging, merging, conflicting or crossing movements around the access point. Access density changes may come from increases because of land development or from decreases due to driveway consolidations or land re-development.

2.2 Operational Impact Related Research

Previous studies have demonstrated that levels of access density are associated with different speed ranges. [14] shows a strong relationship between access density and the 85th percentile speed. Lower access densities are associated with higher speeds so the greater the frequency of access points, the larger the speed reduction to through traffic [29, 30].

Access density is defined by [14] as the number of access points (driveways and intersections) per mile. Most other studies have used the term 'access density' without clearly stating the access points included in the term. While studying the operational impacts, this study [14] measures the access density between features that could control the speeds along the section (e.g., signal, etc.) however; counting of median access points is not included in this definition. Studies have shown that un-signalized access density, signalized access density and median type certainly affect corridor operations and there is a need to understand how these operational impacts change with change in geometric characteristics [25].

Although there is an abundance of research on signalized intersections and their effects on through traffic, little study has explored the effects of access points on the operations of urban streets between signalized intersections. There is a need to explore various methods by which the operational impact of all access points can be studied. A high frequency of closely spaced access points can have a substantial impact on through traffic

[24]. Figures 2 and 3 show the increase in the number of conflict points when driveways are closely spaced.

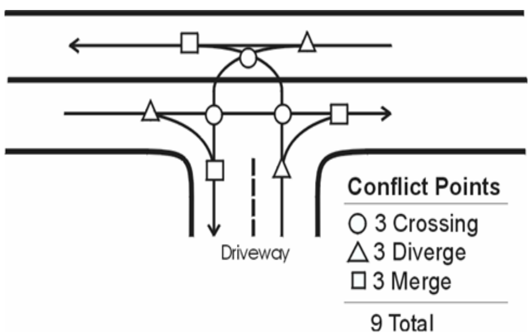


Figure 2: Conflicts in single driveway

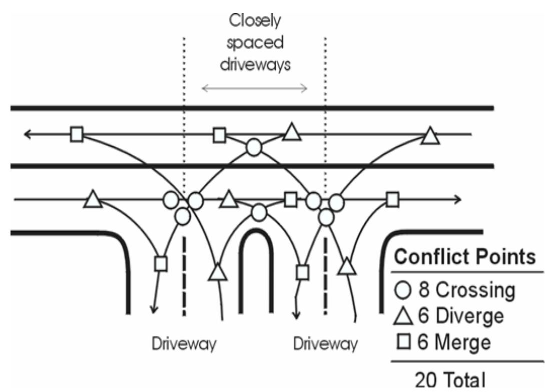


Figure 3 Conflicts in closely spaced driveways

*Source: Statewide Urban Design and Specifications Design Manual Chapter 5.1

While estimating vehicular emissions by capturing traffic variations, access density was found as a significant variable [31, 32]. 32As the number of unrestricted vehicular property access increase there is an increase in vehicle conflict points which has shown result in increases in delays, crash rates and vehicle emissions. Thus accurate measurement of access points and managing them will help save fuel and reduce vehicle emissions which in turn will ensure efficient progression of through vehicles along major roadways, help maintain desired progression speeds and reduce propensity for start and stop traffic operations due to vehicle turning conflicts [32].

As can be seen from the literature presented above, past research indicates that there is a high level of inconsistency in incorporating all access points to compute access density.

The difference in the operational definition of access points is highly dependent on each individual study making it difficult to further research in the area in a consistent and standardized manner. The literature indicates there is a lack of an universal methodology which encompasses all access points and can be applied to all access density research studies.

CHAPTER 3 METHODOLOGY

The access density term and its application were briefly introduced in Chapter 1. In this chapter part 3.1 will describe the three most common methods by which access density has been calculated in the existing studies. Part 3.2 of this chapter further discuss two weighted methodologies for computing access density. The first approach in giving weights to access points involved a combination of subjective judgment and weight assigned based on conflict point ratio of the geometry of access opening. This attempt demonstrated certain limitations such as multiple weighting of same access point which are discussed later in more detail. Improving on this first weighted approach a second weighted approach is proposed which is statistically different from existing computational methods and shows improved correlation to crash data. Based on all the existing and weighted methodologies defined, access data was collected using Google Earth and tables were generated to arrive with access numbers for each definition. The next step is to check the correlation of access points with crash points. Further statistical non-parametric tests are conducted to test the hypothesis that all methods of calculating access density are same.

3.1 Existing Computational Methodology

As seen in chapter 2, past researches point towards existing inconsistency in incorporating all access points to compute access density. Depending on the research objective studies have included only certain access points important for their purpose and excluded other access points. Many studies have defined access point's specific to land use of the study area like commercial driveways, public access driveways, residential driveways and others. However while studying the computation methodologies in existing studies three scenario of computing access points are compared as described in following parts.

3.1.1 Considering Signalized Intersection and Driveways Only

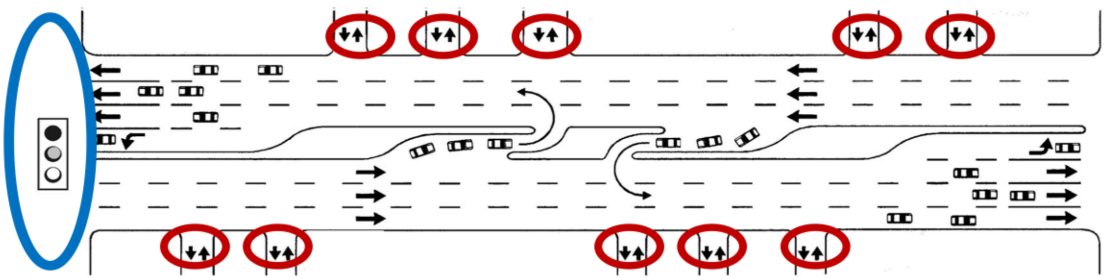


Figure 4: Access Points Considered are Signalized Intersections and Driveways Only

Many research studies ha have proved that number of signalized intersections per mile have a huge impact on safety which results in increased crash incidence. Driven by the importance of the signalized density many studies include midblock driveway points in addition to signalized intersections in their access density computation methods. As a result the un-signalized intersection access points and median access points are not considered in the method.

This is the first scenario of calculating access density from existing methodologies and is referred as 'Definition 1' in the data analysis, statistical tests and conclusions.

For computational use the following equation is used to arrive at access density corresponding to definition 1.

Equation 1: To Calculate Access Density Based on Definition 1

$$\text{Access density} = \frac{\text{(No of signalized intersections + No of driveways)}}{\text{Length of Segment}}$$

3.1.2 Considering Both Intersections and Driveways Only

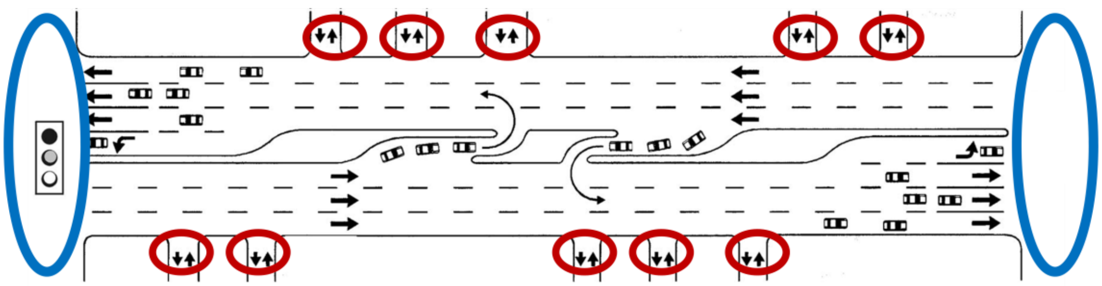


Figure 5: Access Points Considered are Signalized Intersection and Un-signalized Intersections and Driveways Only

In the methodology adopted in this scenario, no distinction is made based on presence of traffic signal thus all intersections (signalized or un-signalized) and driveways in both directions of travel are included in access points while computing access density. The median openings are however not considered even in this methodology. This is the second scenario of calculating access density from existing methodologies and is referred as 'Definition 2' in the data analysis, statistical tests and conclusions.

For computational use the following equation is used to arrive at access density corresponding to definition 1.

Equation 2: To Calculate Access Density Based on Definition 2

$$\text{Access density} = \frac{\text{(No of intersections (signalized or un-signalized) +No of driveways)}}{\text{Length of Segment}}$$

3.1.3 Considering All Intersections, Driveways and Median Openings

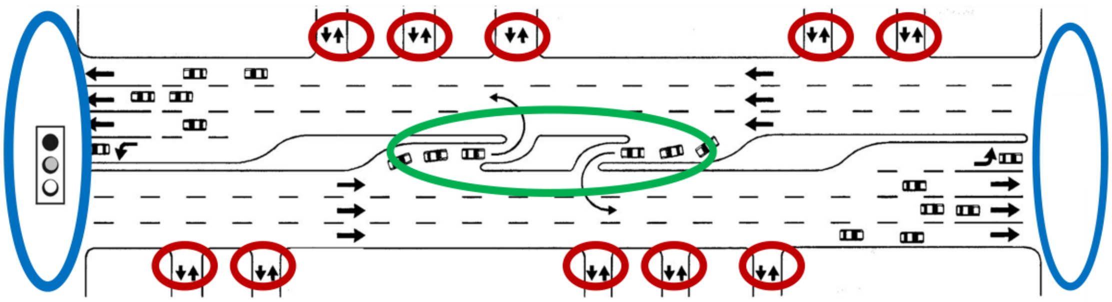


Figure 6: Access Points Considered are All Intersections, Driveways and Median Openings

This is the last methodology which includes all the possible access points on an arterial segment. All components of access points namely signalized intersections, un-signalized intersections, median openings and driveways on both sides of the arterial are included. This is the last scenario of calculating access density from existing methodologies and is referred as 'Definition 3' in the data analysis, statistical tests and conclusions.

For computational use the following equation is used to arrive at access density corresponding to definition 3.

Equation 3: To Calculate Access Density Based on Definition 3

$$\text{Access density} = \frac{\text{(All intersections + No of driveways + No of median openings)}}{\text{Length of Segment}}$$

3.2 Weighted Computational Methodology

The third scenario defined in previous part includes all the access points on the arterial however literature has shown the differences in conflict points for different access openings. It can be clearly understood that impact of single driveway versus impact of a four way intersection could be quite different. The width of driveway opening could potentially have different impact on safety and operational aspects of roadway. To capture the relative difference in these impacts, an attempt has been made to assign weights to different access points based on certain criteria and use it to calculate weighted access density. Two main approaches have been adopted to arrive at the weighted access density and further statistical test are performed to test the improvement from existing methodologies.

3.2.1 Combination of Subjective Judgment and Conflict Point Ratio

The first approach to classify the access points is based on combination of subjective judgment and conflict point ratio of the geometry of the access opening. Various features related to access points are studied and relevant features are identified which could be given weights. Type of intersection (four way or three way), presence or absence of traffic lights, type of median openings and width of driveway openings are identified to assign weights. Subjective judgment is used to assign weights based on driveway width and nature of access points as shown in tables 2 and 3. Figure 7 represents the classification of access points which are identified to assigned weights in this first approach in calculating weighted access density.

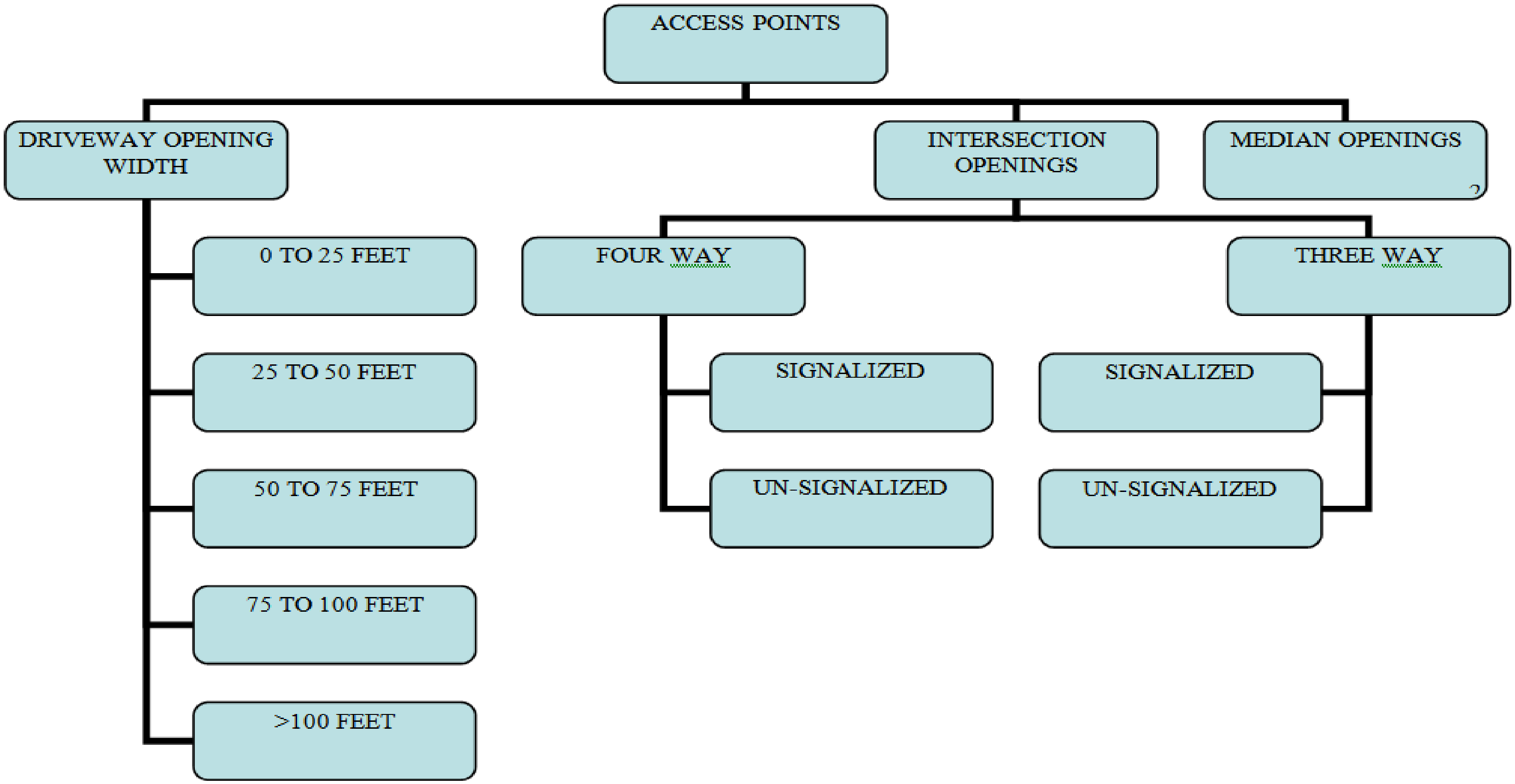


Figure 7: Classification of Access Points for First Approach in Calculating Weighted Access Density

Conflict points are highly correlated with crash rates and are considered as the basis to assign weights to four way and three way intersections. As stated in literature review there is an increased possibility of rear end crashes at signalized four-way and three-way intersections. Intersection area witness higher crashes due to vehicular movements from two driveways and is subjectively weighted higher than single driveway access point. Additionally presence of traffic signal at an intersection results in even higher number of conflicts for proving a subjective weight they are rated even higher. Median openings witness conflicting movements due to change in directions and thus assigned an intermediate weight of 2 between driveway weight of 1 and signalized intersection weight of 3. Un-signalized intersections placed intermediate and assigned equivalent weighted of 2.

Table 2: Subjective Weights Based on Nature of Access Location

No	Description	Subjective Weights
1	Driveways	1
2	Median Openings	2
3	Un-signalized Intersection	2
4	Signalized Intersection	3

Ratio of conflict points between four way intersection and three way intersections are considered to capture the difference in access facilitated by their geometrical configuration. Thus 32:9 is reduced to 3.3:1 which reasonably captures the desired safety impact. Figure 8 shows an Four way intersection and three way intersection in the study area of US 19.

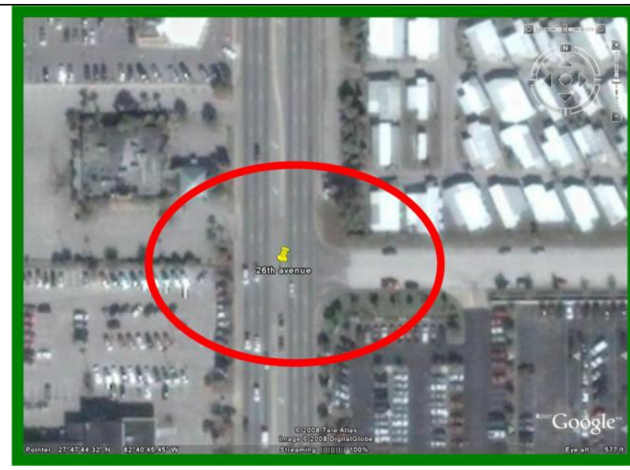
Four-way intersection with 32 conflict points	Three-way intersection with 9 conflict points
	

Figure 8: Aerial View of Intersection Types (US-19)

Another observation was effect of width of driveway opening to safety impact of the arterial segment. Generally wider driveways are an indication of large amount of traffic flow at the access point which indicates larger chance of the crash possibility. Volume of driveway opening could be more appropriate to assign weight for increased crash possibility but it is very difficult to obtain the volume data of various driveway accesses and hence measuring their width and correspondingly applying weights worked out to be practical. Broadly the following categories of driveway widths and their corresponding equivalent weight were used in this first approach of arriving at weighted access density.

Figure 9 shows driveways with different widths.

Table 3: Subjective Weights Based on Driveway / Intersection Width

Driveway / Intersection Width	Equivalent Weight
0 to 25 (feet)	0.5
25 to 50 (feet)	1.0
50 to 75 (feet)	1.5
75 to 100 (feet)	2.0
> 100 (feet)	2.5

Figure 9: Aerial View of Different Widths of Driveways (US-19)

The following equation summarizes the assignment of weights to compute access density adopted in approach 1.

Equation 4: To Calculate Access Density Based on Weighted Approach 1

Access Density = (3 x Signalized Intersection + 2 x Un-signalized Intersection + 2 x Medians + 1 x Driveways) / no. of miles

Where:

Signalized Intersection = 3.3 (If four way intersection)

= 1.0 (If three way intersection)

Driveways = 0.5 when width = 0-25 ft

= 1.0 when width = 25-50 ft

= 1.5 when width = 50-75 ft

= 2.0 when width = 75-100 ft

= 2.5 when width > 100 ft feet

First approach was a preliminary attempt to arrive at weighted methodology which assigned weights to different access points based on above mentioned criteria however it has drawbacks. One of the major drawbacks of this approach was use of subjective judgment which needs to be supported by other findings. Also there was excessive multiple weighting of any access point based on different aspects For example, the driveway openings are weighted 1 and further weighted depending on their width. Similarly median openings and intersection openings were weighted depending on presence /absence of traffic signal and type of intersection.

While conflict points were used to assign weights to four way intersections and three way intersections it is seen that the numbers of conflict points are very sensitive to change in median type associated with the intersections. These detailed conflict points were not considered in this approach.

There are many types of directional median openings with different number of conflict points which have different impacts on the traffic movement. First approach fails to deal with giving subjective weights to two way left turn lanes (TWLTL) which is an additional drawback. A notable inconsistency in the classification of access points as in table 7 is distinction between the terms driveways and intersections. Fundamentally every driveway creates an intersection with the main arterial. Thus we need to clarify what stand we take in incorporating intersections while computing access density. We need to decide if access points should be differentiated as driveways and intersections or fundamentally considered as intersection only for access density computation purpose.

This method talks about one way of assigning subjective weights to various access points however several combinations of weights could be tried to observe changes in correlation values to crash data. Although driveways are assigned a subjective weight 1 we can argue that the traffic movements on driveways are un-controlled as compared to signalized intersections and thus driveways could be potentially more unsafe and should be weighted higher than signalized intersections. Thus effectively we could recalculate the access density with different weights and see how best they correlate crash rate. A detailed sensitivity analysis could result in more appropriate and statistically significant weights however the drawbacks of subjective judgment, multiple weighting and incapability of explaining special access openings like TWLTL do not favor use of this methodology.

Keeping in mind these drawbacks and concerns regarding use of intersection and driveway terminologies a second approach with no subjective judgment is defined. The following part 3.2.2 deals with the second approach of assigning weights by classifying all the possible access points into well defined types.

3.2.2 Proposed Weighted Methodology Based on Detailed Geometry Types

Considering the limitations noticed in the first approach to assign weights to different components while defining access density, there was a need to come up with an objective method of assigning weights. One major inconsistency while computing access density arises when distinction is made between the terms "driveway" and "intersection". Intersections are driveways and thus for access density calculation purpose they should not be split in terms of driveway density and intersection density. Once driveways and intersections are not considered as separate terms one can define all possible geometry types as a combination of intersections and median openings. Intersections can further be three way (driveway on only one side) and four way (driveway on both sides).

With this as basis and eliminating any subjective component, the basic geometry types with all possible permutation and combinations of access locations (say four-way or three-way) and median types (raised / un-divided / directional / TWLTL) are defined in detailed. Once the geometry was identified, conflict points associated with the geometry are worked out. The following conflict points are obtained for each geometry type.

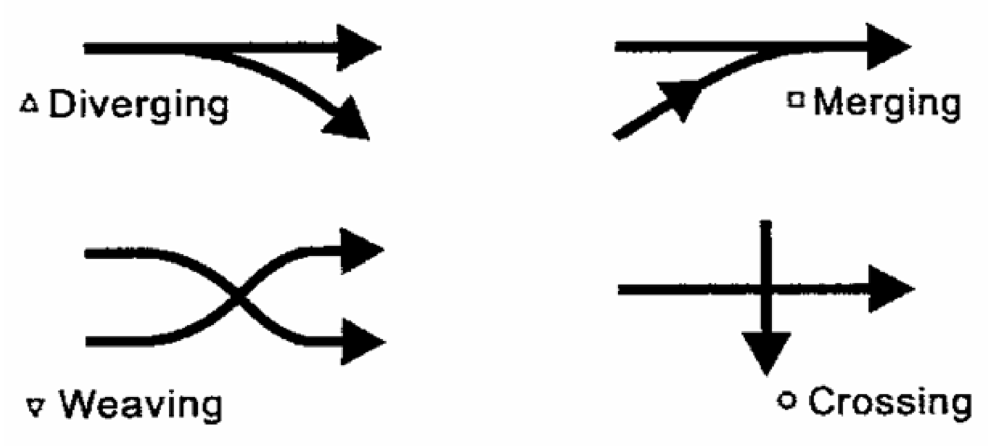


Figure 10: Four Types of Conflicting Movements

Table 4 describes basic five types of three way geometry type and Table 5 describes basic five types four way geometry type. Different type of median arrangements are incorporated in these types and based on the conflict points of the geometry they are assigned equivalent weight.

All the three major components of access density namely, driveways, intersections and median openings are incorporated in these geometry types. Types 1 to type 5 are the most common geometries associated with three way intersection (driveways are considered as intersection). Similarly types 6 to type 10 are the commonly found geometries associated with four legged intersections.

Type 1 which represents a typical single access opening with full median access is considered as base condition and assigned an equivalent weight of 1. The equivalent weights of all other types are calculated with type 1 as base and are summarized in table 6 (Page 31).

Tables 4 and table 5 describe the geometry of each access type, their median opening, number of conflict points and calculated equivalent weights. Once the weights are obtained the next step is to find the number of these types in the selected roadway arterial.

Using the equivalent weights and number of each type, following equation can be used to arrive at the weighted access density.

Equation 5: To Calculate Access Density Based on Weighted Approach 2

Weighted access density = [(1 x # Type 1) + (2.2 x # Type 2) + (0.2 x # Type 3) + (0.6 x # Type 4) + (0.6 x # Type 5) + (3.6 x # Type 6) + (0.4 x # Type 7) + (0.8 x # Type 8) + (0.8 x # Type 9) + (0.1 x # Type 10) + (W^{x1} x #Type X_1) + (W^{x2} x # Type X_2)]

/ Length of the segment.

Table 4: Details of Three Way Geometry Types in Proposed Weighted Methodology

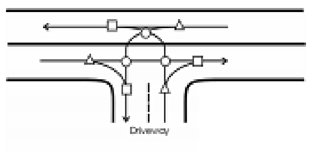
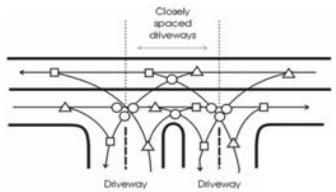
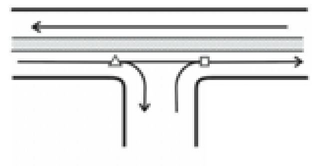
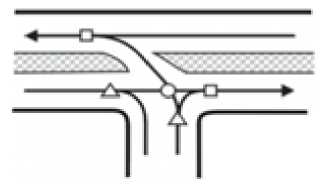
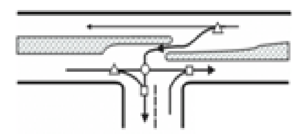
TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5
				
Number of lanes = 2 Median type = Undivided Access = single entrance	Number of lanes = 2 Median type = Undivided Access = closely spaced entrance	Number of lanes = 2 Median type = Raised Access = single entrance	Number of lanes = 2 Median type = Raised Access = left turn egress only from intersection or driveway	Number of lanes = 2 Median type = Raised Access = left turn ingress only into driveway or driveway
Conflict Points = 9	Conflict Points = 20	Conflict Points = 2	Conflict Points = 5	Conflict Points = 5
Weighted Access Equivalent = 1	Weighted Access Equivalent = 2.2	Weighted Access Equivalent = 0.2	Weighted Access Equivalent = 0.6	Weighted Access Equivalent = 0.6

Table 5: Details of Four Way Geometry Types in Proposed Weighted Methodology

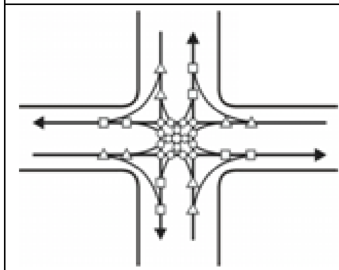
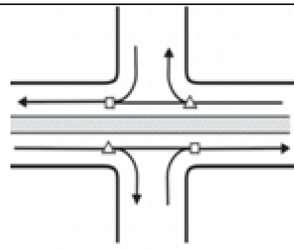
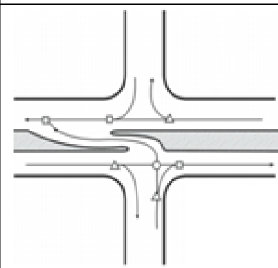
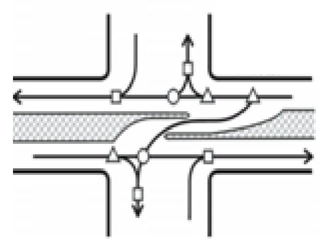
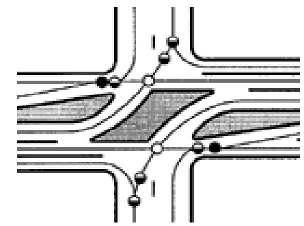
TYPE 6	TYPE 7	TYPE 8	TYPE 9	TYPE 10
				
Number of lanes = 2 Median type = Undivided Access = typical four-way intersection or driveway	Number of lanes = 2 Median type = Raised Access = typical four-way intersection or driveway	Number of lanes = 2 Median type = Raised Access = left turn egress only from intersection or driveway	Number of lanes = 2 Median type = Raised Access = left turn ingress only into driveway	Number of lanes = 2 Median type = Raised Access = left turn into driveways from both direction lanes
Conflict Points = 32	Conflict Points = 4	Conflict Points = 7	Conflict Points = 7	Conflict Points = 10
Weighted Access Equivalent = 3.6	Weighted Access Equivalent = 0.4	Weighted Access Equivalent = 0.8	Weighted Access Equivalent = 0.8	Weighted Access Equivalent = 1.1

Table 6: Summary of Equivalent Weights in the Proposed Weighted Methodology

Category of "types" defined above	Equivalent Weight
*Type 1	1
*Type 2	2.2
*Type 3	0.2
*Type 4	0.6
*Type 5	0.6
*Type 6	3.6
*Type 7	0.4
*Type 8	0.8
*Type 9	0.8
*Type 10	1.1

*Types correspond to the description provided in table 4 and table 5

Although these ten types constitute the primary set of geometry types commonly found in urban arterials there is always room for other access types. With advancement in median treatments and adoption of newer configurations of medians, one would have to calculate their conflict points and reduce it using the equation and obtain its equivalent weight This second approach of assigning weights to access points provides flexibility to incorporate additional geometry types and arriving at the weighted access equivalent by diving their conflict points by '9' which corresponds to type 1 described in table 4.

Equation 6: To Calculate Equivalent Weight for Second Approach

$$\text{Equivalent weight} = \frac{\text{Number of conflict points in the given geometry}}{9}$$

Although the study area of US-19 does not have any Two Way Left Turn Lane (TWLTL) we can come up with its equivalent weight by calculating the number of conflict points as shown in the Figure 11. As TWLTL has 30 conflict points and based on the formula above it is assigned equivalent access weight of 3.33.

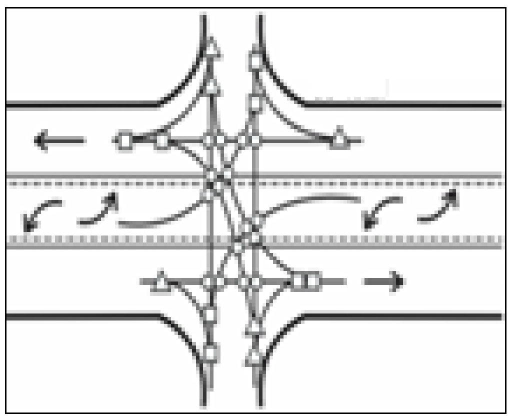


Figure 11: Conflict Points Associated with Two Way Left Turn Lanes (TWLTL)

Thus the weighted access density can be obtained which can then be used to correlate with the crash rates. These correlations are the key to draw conclusions.

CHAPTER 4 DATA COLLECTION

4.1 Study Location

Figure 12: Study Location

The selected roadway segment is the US 19 in the Pinellas County, Florida. The most commonly seen access points along this major arterial are driveways with commercial land use. Length of entire arterial is of 32 miles which is a 3 + 3 multilane arterial in FDOT district-7. The posted average speed limit on US 19 is 55 mph. It is classified under urban and other principal arterial. For purpose of studying the access points, 15 miles stretch of road in South

Pinellas was included. Appendix A shows the straight line diagram of the selected 15 miles obtained from FDOT. These straight line diagrams were used to connect the access data with crash data using mile post as the common variable.

4.2 Data Collection

4.2.1 Access Data

Access details for the selected roadway segment are obtained from Google Earth and Google Maps (See appendix B). The access details are represented in GIS maps as seen in figure 15. About 420 access points are identified in the 15 miles of selected roadway.

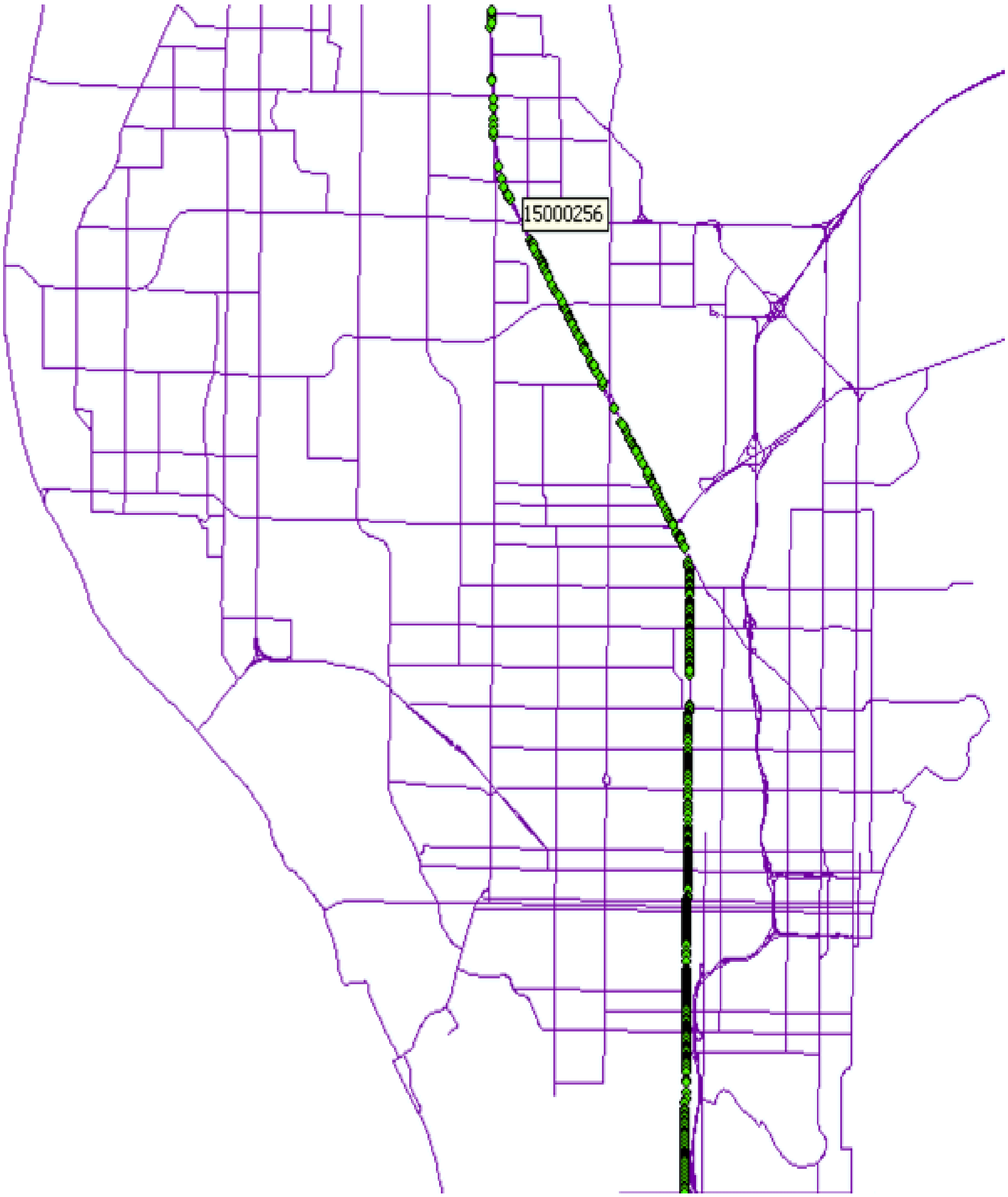


Figure 13: Location of Access Points along the Selected Roadway Arterial

Table 7: Access Data Collected for the Selected Roadway Segment

Mile Post		Four way intersection		Three way intersection		Driveway		Median
Start	End	Signalized	Un-signalized	Signalized	Un-signalized	N bound	S bound	Total
0.87	1	1	0	0	0	1	4	0
1	2	4	4	0	4	27	16	1
2	3	2	5	0	2	17	27	0
3	4	2	4	0	11	31	28	1
4	5	5	8	0	4	42	48	2
5	6	3	11	0	3	19	25	0
6	7	2	7	0	6	32	27	0
7	8	1	1	0	3	19	18	1
8	9	4	5	0	1	28	26	1
9	10	3	0	0	0	24	18	4
10	11	1	0	0	0	15	7	5
11	12	1	3	0	0	11	7	2
12	13	1	0	0	0	14	11	0
13	14	0	0	0	0	7	10	0
14	15	0	0	0	0	11	3	0

4.2.2 Crash Data

Data for the number of crashes and annual average daily traffic (AADT) along arterial is collected for five years from 2002 to 2006. It is very important to have good quantity and fairly consistent crash data before using it for correlating with access points. The five year data is checked to make sure it is free from any obvious abnormalities in occurrences along the mileposts of the selected roadway. Figure 13 shows that numbers of crashes in the five years does not show lot of variation in trend and hence the summation of crashes can be used to arrive at crash rates of the selected roadway segment.

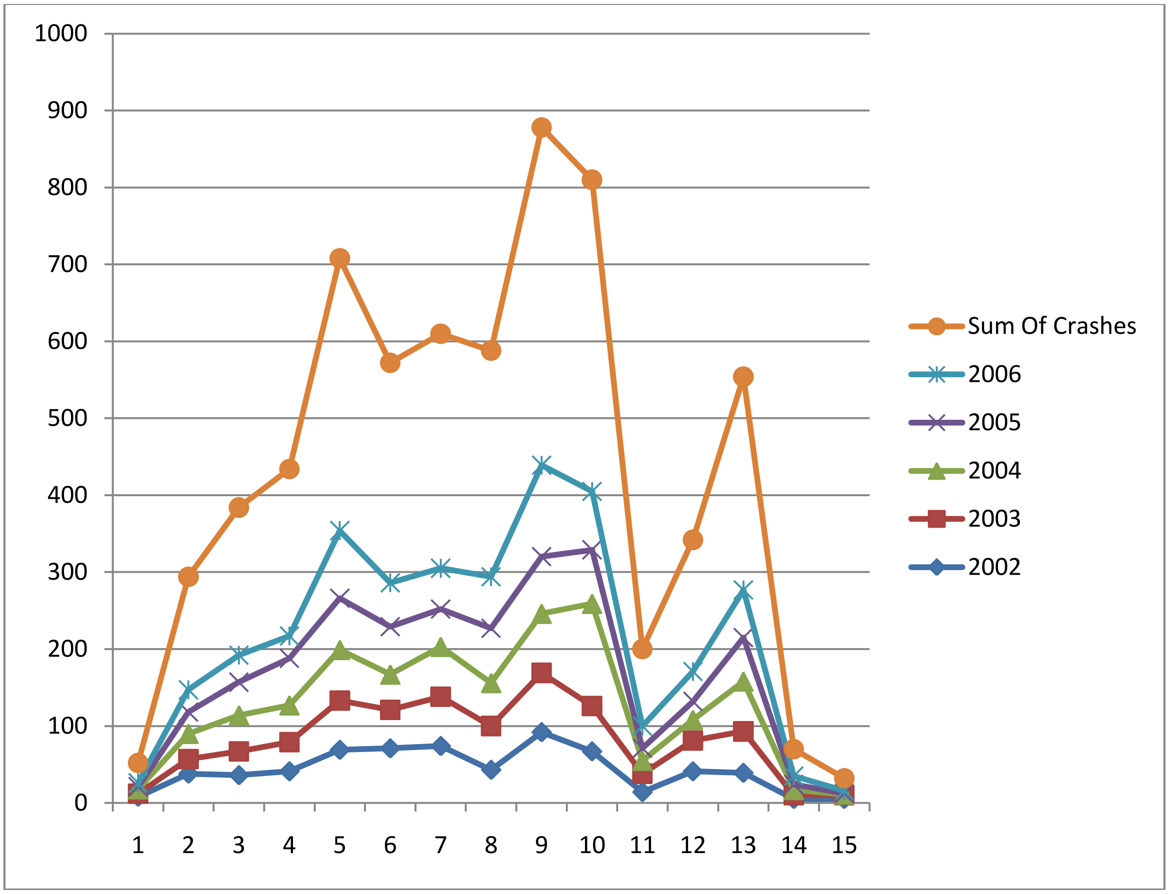


Figure 14: Trend of Number of Crashes from 2002 – 2006

A total of 3264 number of crashes were used to arrive at crash rate of the selected roadway segment. These are located over the entire stretch of the urban arterial under study.

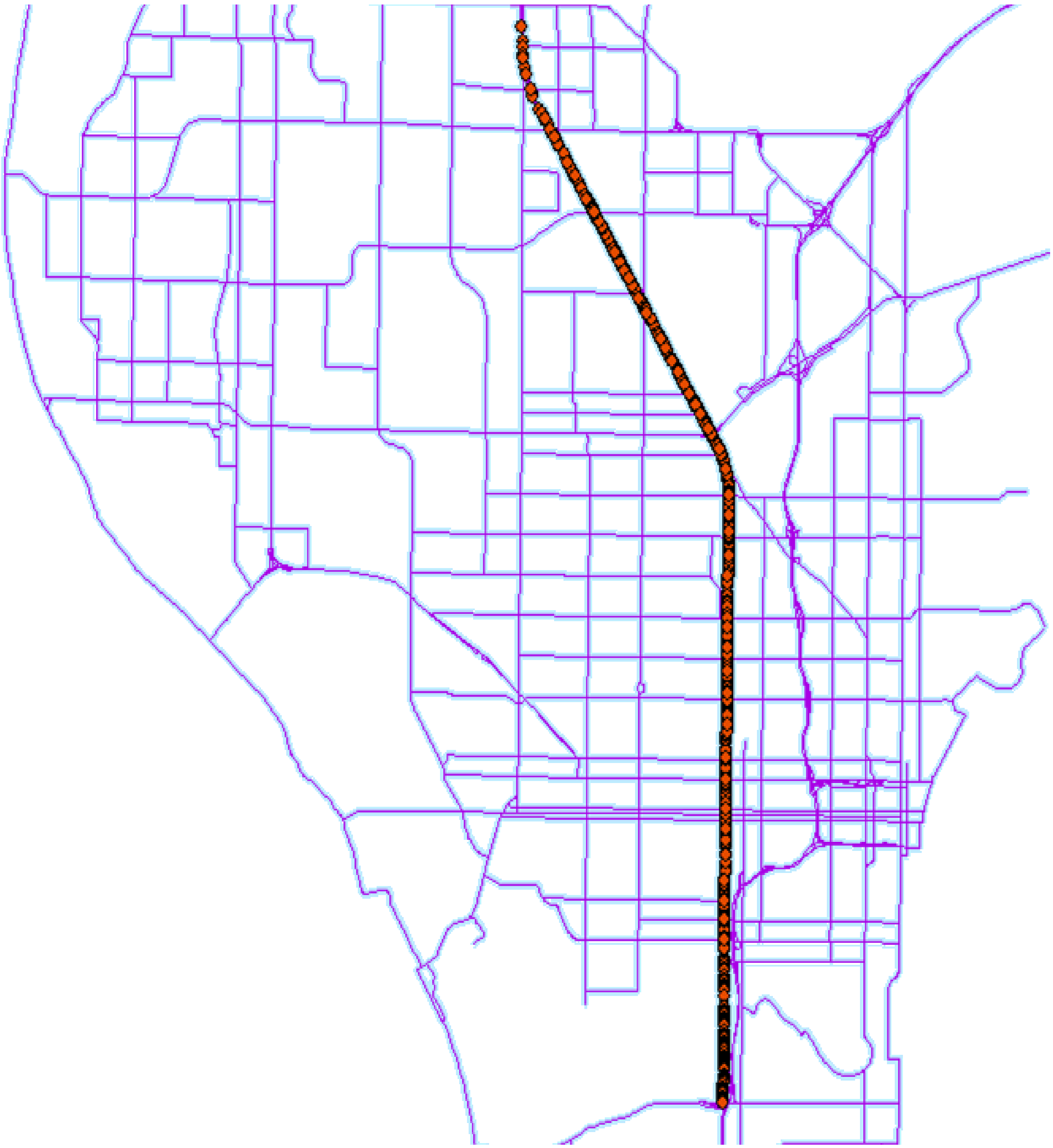


Figure 15: Location of Crash Points along the Selected Roadway Arterial

Crash rates are calculated for each mile as a function of number of crashes, volume and length in terms of crashes per million vehicle miles traveled.

$$R = \frac{1{,}000{,}000 * A}{365 * T * V * L}$$

Where:

1. R is crash rate for the section (in crashes per MVMT)
2. A is the number of reported crashes
3. T is time frame of the data (years)
4. V is AADT of the road section
5. L is the length of the segment (miles)

Table 8: Crash Rate of the Selected Roadway Segment

Mile Post		No Of Crashes	AADT	Crash Rate (crashes per MVMT)
Start	End			
0.87	1	26	26500	4.14
1	2	147	27345	2.45
2	3	192	34140	2.57
3	4	217	42500	2.33
4	5	354	42435	3.81
5	6	286	42420	3.08
6	7	305	45500	3.06
7	8	294	45500	2.95
8	9	439	48305	4.15
9	10	405	67775	2.73
10	11	100	69500	0.66
11	12	171	69500	1.12
12	13	277	69500	1.82
13	14	35	44450	0.36
14	15	16	44000	0.17

CHAPTER 5 DATA ANALYSIS

5.1 Existing Methodology

Data was analyzed by applying the proposed methodology using the collected access and crash data obtained from previous chapters. Following table summarizes the resultant average access densities based on the three existing methods as discussed in chapter 3.1. The entire data set of access points and crash points has been broken down into 15 points of one mile.

Table 9: Summary of Average Access Density Based on Existing Methodology

Mile Post		Definition 1	Definition 2	Definition 3
Start	End			
0.87	1	4	4	4
1	2	23	31	32
2	3	28	35	35
3	4	27	42	43
4	5	61	73	75
5	6	13	27	27
6	7	31	44	44
7	8	28	32	33
8	9	38	44	45
9	10	39	39	43
10	11	21	21	26
11	12	11	14	16
12	13	24	24	24
13	14	17	17	17
14	15	14	14	14
Average access densities:		27 points/ mile	33 points/ mile	34 points/ mile

Correlation of access density and crash rates is performed to arrive at correlation values for each definition. The R square values obtained are summarized in the following table

Table 10: Comparison of the Three Definitions from Literature Review

No	Access Points included	Access Density	Correlation	Relative improvement (%)	Comments
1	Both direction driveways + Signalized Intersections	27	0.42	Nil	Base condition
2	Both direction driveways + Signalized Intersections + Un-signalized Intersections	33	0.50	19 %	Improvement from base condition
3	Both direction driveways + Signalized Intersections + Un-signalized Intersections + Median Openings	34	0.48	14%	Improvement from base condition

5.2 Weighted Methodology

There are two methods which are adopted to arrive at weighted access density. The first method is a combination of subjective and objective judgment which assigned the weights to the access components as discussed in chapter 3.2. Table 11 shows the effective weights which are used in access density calculations.

Table 11: Effective Weights Assigned in First Approach of Weighted Methodology

	Four way intersection		Three way intersection		Driveway					Median
	Signalized	Un-signalized	Signalized	Un-signalized	0-25	25-50	50-75	75-100	> 100	
Subjective	3	2	3	2	0.5	1	1.5	2	2.5	2
Objective	3.3	3.3	1	1						
NET	9.9	6.6	3	2	0.5	1	1.5	2	2.5	2

Tables 12 and 13 show the calculations to arrive at average weighted access density by the two approaches. Once the weighted access density is calculated correlation of weighted access density and crash rates are performed.

Table 12: Access Density Calculations Based on First Methodology

Mile Post		Four way intersection		Three way intersection		Driveway					Median Opening	Access Density
Start	End	Signalized	Un-signalized	Signalized	Un-signalized	0-25	25-50	50-75	75-100	> 100		
0.87	1	9.9	0	0	0	0.5	2	0	2	0	0	14.4
1	2	39.6	26.4	0	8	4.5	20	1.5	0	0	2	102
2	3	19.8	33	0	4	5.5	18	4.5	2	0	0	86.8
3	4	19.8	26.4	0	22	13	21	1.5	0	0	2	105.7
4	5	49.5	52.8	0	8	10	37	10.5	0	2.5	4	174.3
5	6	29.7	72.6	0	6	4	18	4.5	0	0	0	134.8
6	7	19.8	46.2	0	12	7	21	3	2	0	0	111
7	8	9.9	6.6	0	6	3.5	13	3	2	0	2	46
8	9	39.6	33	0	2	1.5	27	3	0	0	2	108.1
9	10	29.7	0	0	0	3	16	6	0	0	8	62.7
10	11	9.9	0	0	0	0	11	6	4	0	10	40.9
11	12	9.9	19.8	0	0	0.5	12	6	0	0	4	52.2
12	13	9.9	0	0	0	0.5	15	6	0	2.5	0	33.9
13	14	0	0	0	0	1.5	8	4.5	2	0	0	16
14	15	0	0	0	0	0.5	10	3	0	0	0	13.5
AVERAGE ACCESS DENSITY BY APPROACH 1 =												78

Table 13: Access Density Calculations Based on Second Methodology (Proposed Methodology)

Mile Post		Type 1		Type 2		Type 3		Type 4		Type 5		Type 6		Type 7		Type 8		Type 9		Type 10		Access Density
Start	End																					
CONFLICTS		9		20		2		5		5		32		4		7		7		10		
WEIGHTS		1.0		2.2		0.2		0.6		0.6		3.6		0.4		0.8		0.8		1.1		
			Wt		Wt		Wt		Wt		Wt		Wt		Wt		Wt		Wt		Wt	
0.87	1	0	0	0	0.0	3	0.7	0	0	0	0.0	1	3.6	0	0.0	0	0	0	0.0	0	0.0	4.2
1	2	4	4	1	2.2	13	2.9	0	0	0	0.0	8	28.4	3	1.3	0	0	1	0.8	0	0.0	39.7
2	3	2	2	1	2.2	18	4.0	0	0	0	0.0	7	24.9	5	2.2	0	0	0	0.0	0	0.0	35.3
3	4	11	11	0	0.0	28	6.2	0	0	0	0.0	6	21.3	2	0.9	0	0	1	0.8	0	0.0	40.2
4	5	4	4	0	0.0	34	7.6	0	0	0	0.0	13	46.2	12	5.3	0	0	2	1.6	0	0.0	64.7
5	6	3	3	0	0.0	10	2.2	0	0	0	0.0	11	39.1	5	2.2	0	0	0	0.0	0	0.0	46.6
6	7	6	6	0	0.0	10	2.2	0	0	0	0.0	9	32.0	13	5.8	0	0	0	0.0	0	0.0	46.0
7	8	3	3	0	0.0	9	2.0	0	0	0	0.0	2	7.1	8	3.6	0	0	1	0.8	0	0.0	16.4
8	9	1	1	0	0.0	9	2.0	0	0	0	0.0	9	32.0	12	5.3	0	0	0	0.0	1	1.1	41.4
9	10	0	0	0	0.0	9	2.0	0	0	0	0.0	1	3.6	12	5.3	0	0	0	0.0	4	4.4	15.3
10	11	0	0	0	0.0	8	1.8	0	0	1	0.6	1	3.6	3	1.3	0	0	1	0.8	3	3.3	11.3
11	12	0	0	0	0.0	12	2.7	0	0	0	0.0	3	10.7	0	0.0	0	0	0	0.0	2	2.2	15.6
12	13	0	0	0	0.0	17	3.8	0	0	0	0.0	1	3.6	3	1.3	0	0	0	0.0	0	0.0	8.7
13	14	0	0	0	0.0	13	2.9	0	0	0	0.0	0	0.0	2	0.9	0	0	0	0.0	0	0.0	3.8
14	15	0	0	0	0.0	12	2.7	0	0	0	0.0	0	0.0	1	0.4	0	0	0	0.0	0	0.0	3.1
AVERAGE ACCESS DENSITY BY APPROACH 2 =																						28

5.3 Comparison of Existing and Weighted Methodology

Table 14: Summary of Correlation Results of Access Density Computational Methods

Various Definitions	Access points included	Access Density	Correlation values with crash rate	Relative Improvement (%)
Definition 1	Both direction driveways + Signalized Intersections	27	0.42	Base condition
Definition 2	Both direction driveways + Signalized Intersections + Un-signalized Intersections	33	0.50	19%
Definition 3	Both direction driveways + Signalized Intersections + Un-signalized Intersections + Median Openings	34	0.48	14%
Weighted Method 1	Weights based on subjective judgment + Conflict point	78	0.58	38%
Weighted Method 2	Weights based on geometry types based on only conflict points	28	0.59	40%

Weighted methods for computing access density show an improvement of about 40% from the definition 1 of existing methods which includes signalized intersections and midblock driveway openings only. Providing weights to access points certainly improves the correlation values between access density and crash rates. There is not much difference between correlation values of weighted method 1and weighted method 2 values; however weighted method 2 has clear benefits as compared to the drawbacks found in weighted method 1.

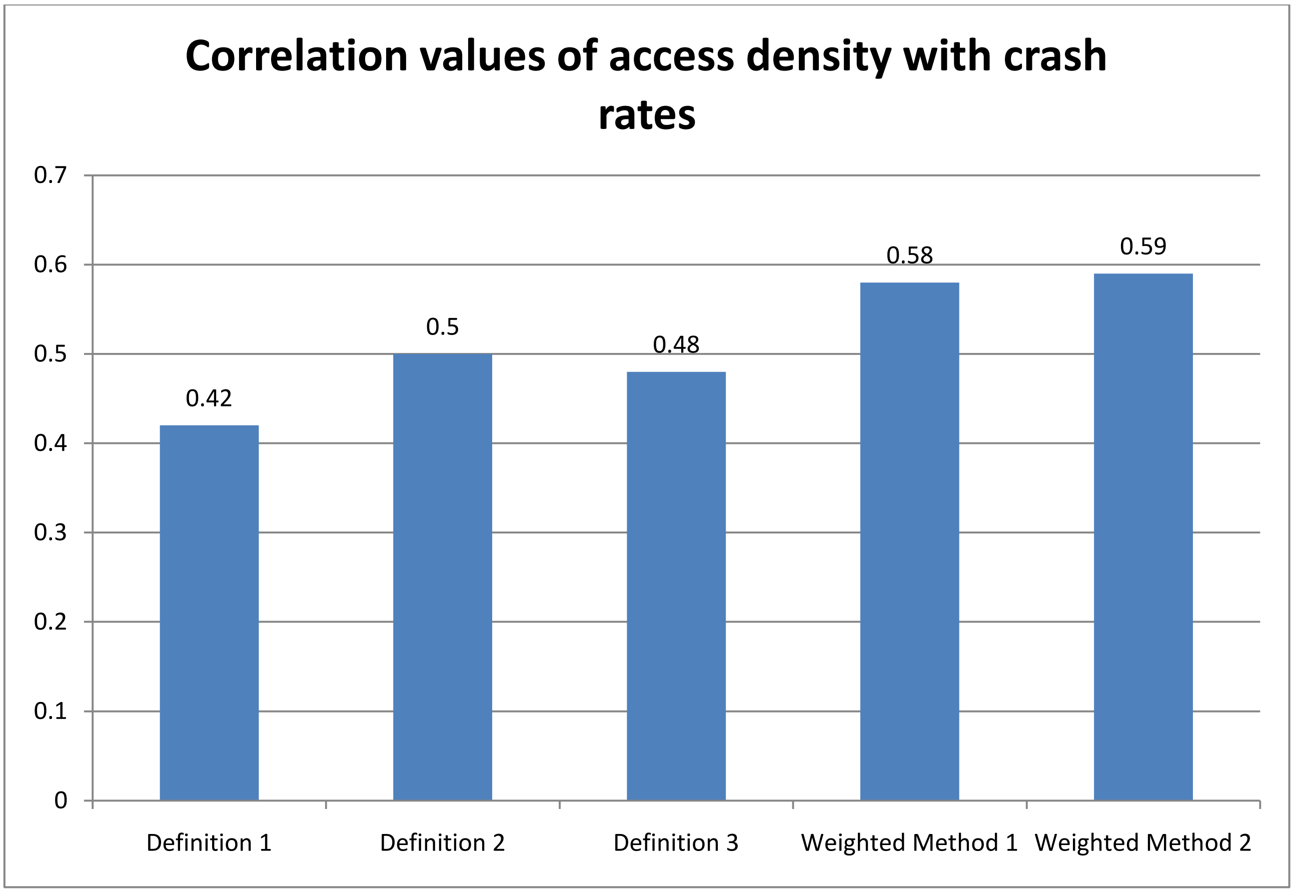


Figure 16: Final Correlation Results

CHAPTER 6 STATISTICAL ANALYSIS

While comparing the access density values obtained by the five methodologies explained in previous chapters, it is very important to check if they are significantly different from each other and if the improvement is worth the effort. Descriptive statistics of numerical methods and graphical representation can be used to summarize and interpret data. Numerical methods have an advantage over graphical representation methods as they provide precise and objective determined values that can be easily manipulated, interpreted and compared. Thus numerical method has been used to statistically test the results obtained in chapter 5.

Hypothesis testing is used to determine whether the differences in access density have arisen by chance or whether some other factor is responsible for the difference. To formulate a hypothesis testing, two competing statistical hypothesis namely null hypothesis and alternative hypothesis are formulated. Null hypothesis is an assertion about a population parameter that is assumed to be true until there is sufficient statistic evidence to conclude otherwise. Based on the objective to determine if the various definitions are same or different a null hypothesis is defined. The purpose of defining the hypothesis is that when it gets rejected it shows that the definitions are different.

Kruskal Wallis is used to test the effect of access density obtained by various definitions. This test has been performed three times to test the following aspects.

1. To test if the existing three methods of computing access density are statistically different.
2. To test if the two weighted methods of computing access density are statistically different.
3. To test if the definition 3 (which counts all access points) and weighted method 2 (which in comparison has the best correlation) are statistically different.

This non-parametric test was performed with 95% level of confidence. For performing a Kruskal Wallis test null hypothesis to be tested is formulated. The observations to be tested are then ranked for each group and sum of their ranks is obtained. Test statistic is then calculated using the sum of ranks of each group. Critical chi square value is obtained for k-1 degrees of freedom. Test statistic is further compared to critical statistic and inferences are drawn about the null hypothesis.

6.1 Comparing the Three Existing Methods of Computing Access Density

A non parametric Kruskal-Wallis test is conducted with the following steps to arrive at conclusions.

1. Null Hypothesis (Ho) -The three existing methods of computing access density are the same.
2. Calculated test statistic = 2.0199
3. Level of confidence = 95%
4. Critical Statistic = 5.9915
5. As Test Statistic < Critical Statistic, we have no evidence to reject Null Hypothesis

Conclusion: The three methods of computing access density are not significantly different from each other.

Table 15: Access Points Breakdown for Three Existing Methods

Observation No	Definition 1	Definition 2	Definition 3
1	4	4	4
2	23	31	32
3	28	35	35
4	27	42	43
5	61	73	75
6	13	27	27
7	31	44	44
8	28	32	33
9	38	44	45
10	39	39	43
11	21	21	26
12	11	14	16
13	24	24	24
14	17	17	17
15	14	14	14

6.2 Comparing the Two Weighted Methods of Computing Access Density

A non parametric Kruskal-Wallis test is conducted with the following steps to arrive at conclusions.

1. Null Hypothesis (Ho) - Two weighted methods of computing access density are the same.
2. Calculated test Statistic = 8.19
3. Level of confidence = 95%
4. Critical Statistic = 3.8415
5. As Test Statistic > Critical Statistic, we reject Null Hypothesis

Conclusion: The two weighted methods of computing access density are significantly different from each other.

Table 16: Access Points Breakdown for Two Weighted Methods

Observation No	Weighted Definition 1	Weighted Definition 2
1	14.4	4.2
2	102	39.7
3	86.8	35.3
4	105.7	40.2
5	174.3	64.7
6	134.8	46.6
7	111	46.0
8	46	16.4
9	108.1	41.4
10	62.7	15.3
11	40.9	11.3
12	52.2	15.6
13	33.9	8.7
14	16	3.8
15	13.5	3.1

6.3 Comparison of Existing and Weighted Methodology

A non parametric Kruskal-Wallis test is conducted with the following steps to arrive at conclusions.

1. Null Hypothesis (Ho) - Access density calculated by weighted method is same as access density calculated by existing methods
2. Calculated test statistic = 4.723
3. Level of confidence = 95%
4. Critical Statistic = 3.8415
5. As Test Statistic > Critical Statistic, we reject Null Hypothesis

Conclusion: The two methods of computing access density are significantly different from each other with LOC =95%.

Table 17: Access Point Breakdown for Definition 1 and Weighted Method 2

Observation No	Definition 3	Weighted Definition 2
1	4	4.2
2	32	39.7
3	35	35.3
4	43	40.2
5	75	64.7
6	27	46.6
7	44	46.0
8	33	16.4
9	45	41.4
10	43	15.3
11	26	11.3
12	16	15.6
13	24	8.7
14	17	3.8
15	14	3.1

Thus in conclusion the three Kruskal Wallis statistically confirms the main result that the weighted access density calculated by second approach is significantly different from existing definition and it not a matter of chance that weighted methodology access density values appear to be improved.

Table 18: Summary of Statistical Results

No	Null Hypothesis:	Kruskal Wallis Result
1	Three existing methods of computing access density are the same	No evidence to reject null hypothesis
2	Two weighted methods of computing access density are the same	Reject null hypothesis
3	Definition 3 of existing methods and definition 2 of weighted methods have the same access density	Reject null hypothesis

CHAPTER 7 CONCLUSIONS

Being able to define a systematic approach to incorporate the different access points while computing access density for an urban arterial segment is an important area in arterial management. Access density appears to be a simple terminology, however inconsistent usage of the term results in inconsistent numerical value which makes it difficult to compare access density results from two different studies. There are many other factors like number of lanes, traffic volume on driveways, type of channelization which affects the crash rate which are not included in the study and main focus is on computational methods of access density. This study compares the different existing computational methods of calculating access density and further proposed a weighted method that is capable of capturing impacts of different types of access points. With this weighted methodology, we are a step closer to improved and clearly defined definition which could be applied in areas of safety, operational and planning areas.

Non-parametric statistical tests were performed to test if the improvement between the existing and proposed methodologies is significantly different. There was no evidence to show that three existing methods of defining access density are different however the proposed weighted methodology was found to be significantly different and correlation values indicate an improvement with reference to explaining the crashes on the selected urban arterial.

Assigning subjective weights to various access types does improve the correlation of access density value with crash rates. This study has adopted one set of weights however more combinations of different weights could be tried to arrive at improved weights; however assigning subjective weights arises various questions. Statistically the difference in the access density calculated by proposed methodology and that of existing methodology is significantly different.

Recommended Weighted Methodology

For convenience, the computational method to arrive at weighted access density can be simplified in four simple steps:

1. Develop a straight line diagram and keep categorizing the access points into one of the types as defined in Tables 4 and 5.
2. Any access points which do not fall into the 10 types defined should be considered as a special case (say type X_1 and X_2 and so on) and quickly capture the geometry to arrive at number of conflicts points corresponding to the geometry.
3. Use the formula of dividing the conflict points by 9 to arrive at the weight (say W_{x1} and W_{x2} and so on) for the special access opening.
4. Weighted access density can now be calculated as:

$$\frac{\sum \text{(Weight for type X) x (number of type X access)}}{\text{Length of the segment}}$$

Where X ranges from 1 to 10 as described in tables 4 and 5.

Advantages of using this weighted methodology is that it requires easy steps as described above. Unlike the first weighted approach it can be applied to two way left turn lanes (TWLTL) and does not result in multiple assignment of weights to same access points. Most importantly there is transparency in assigning weights and flexibility of accommodating special access types.

Recommendations

1. A consistently used standard method should exist to compute access density.
2. All three components should be considered
    i. Both direction driveways
    ii. Type of intersections (signalized + un-signalized)
    iii. Type of median openings
3. To incorporate the impact of different access points a weighted approach to compute access density must be adopted.
4. Eliminate subjective judgment and use conflict points as a measure to assign weights.

This study has adopted one set of weights however more combinations of different weights could be tried to arrive at improved weights based on subjective judgment. The recommended approach of assigning objective weights based on geometry types has clear advantages based on the study findings.

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APPENDICES

APPENDIX A. Straight Line Diagrams

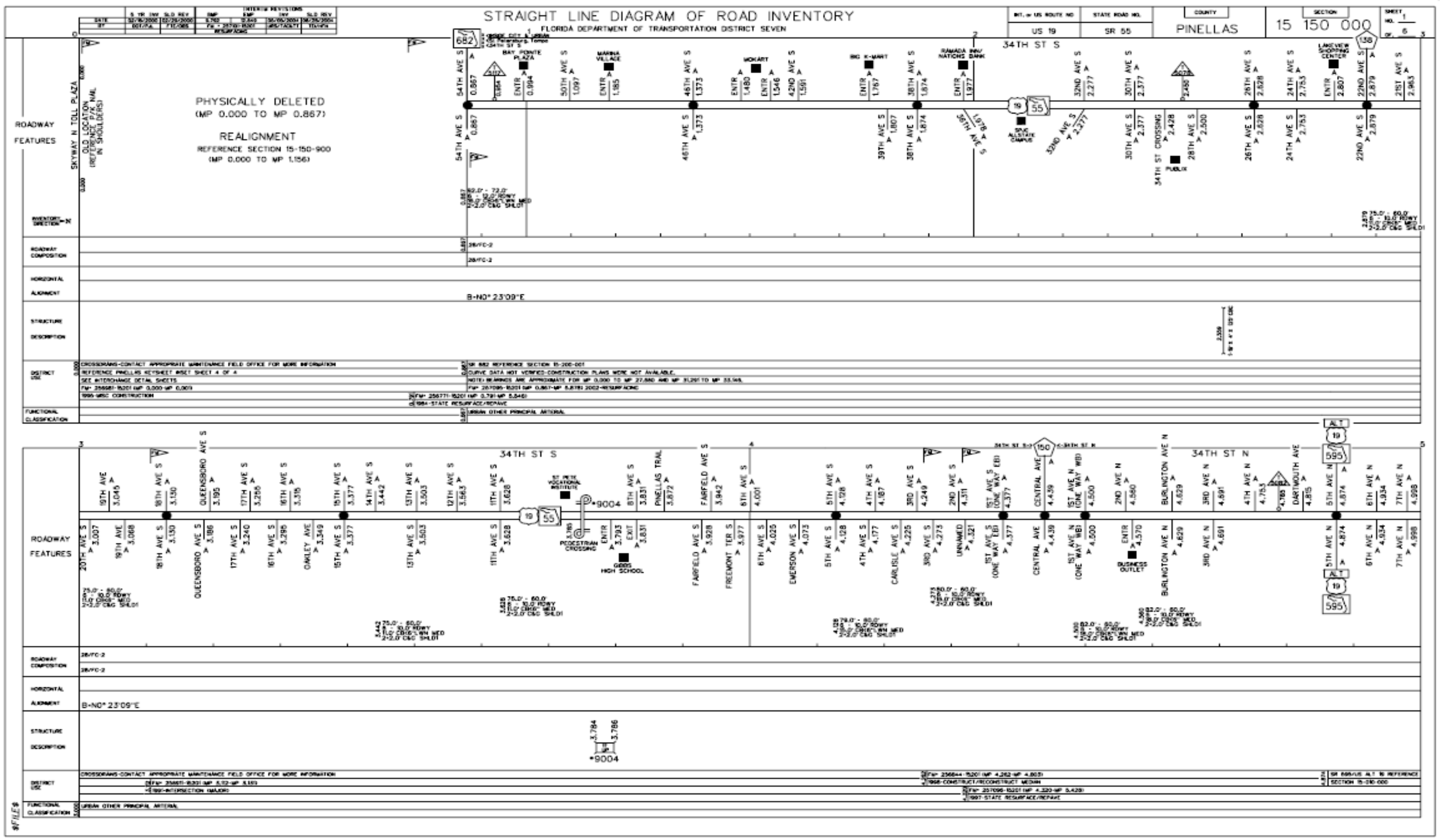

Figure 17: SLD from Milepost 0 to Milepost 5

APPENDIX A (Continued)

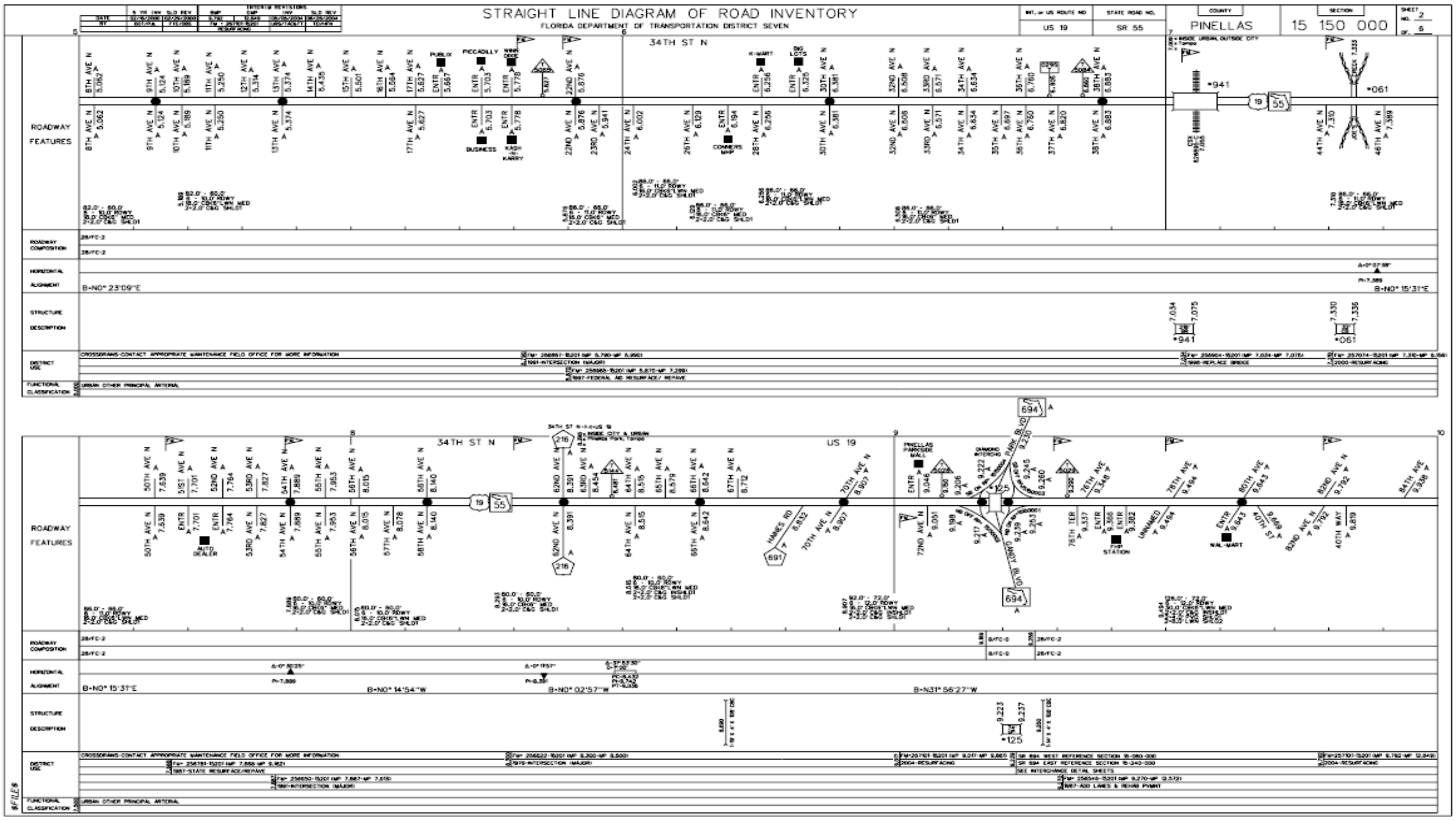

Figure 18: SLD from Milepost 5 to Milepost 10

APPENDIX A (Continued)

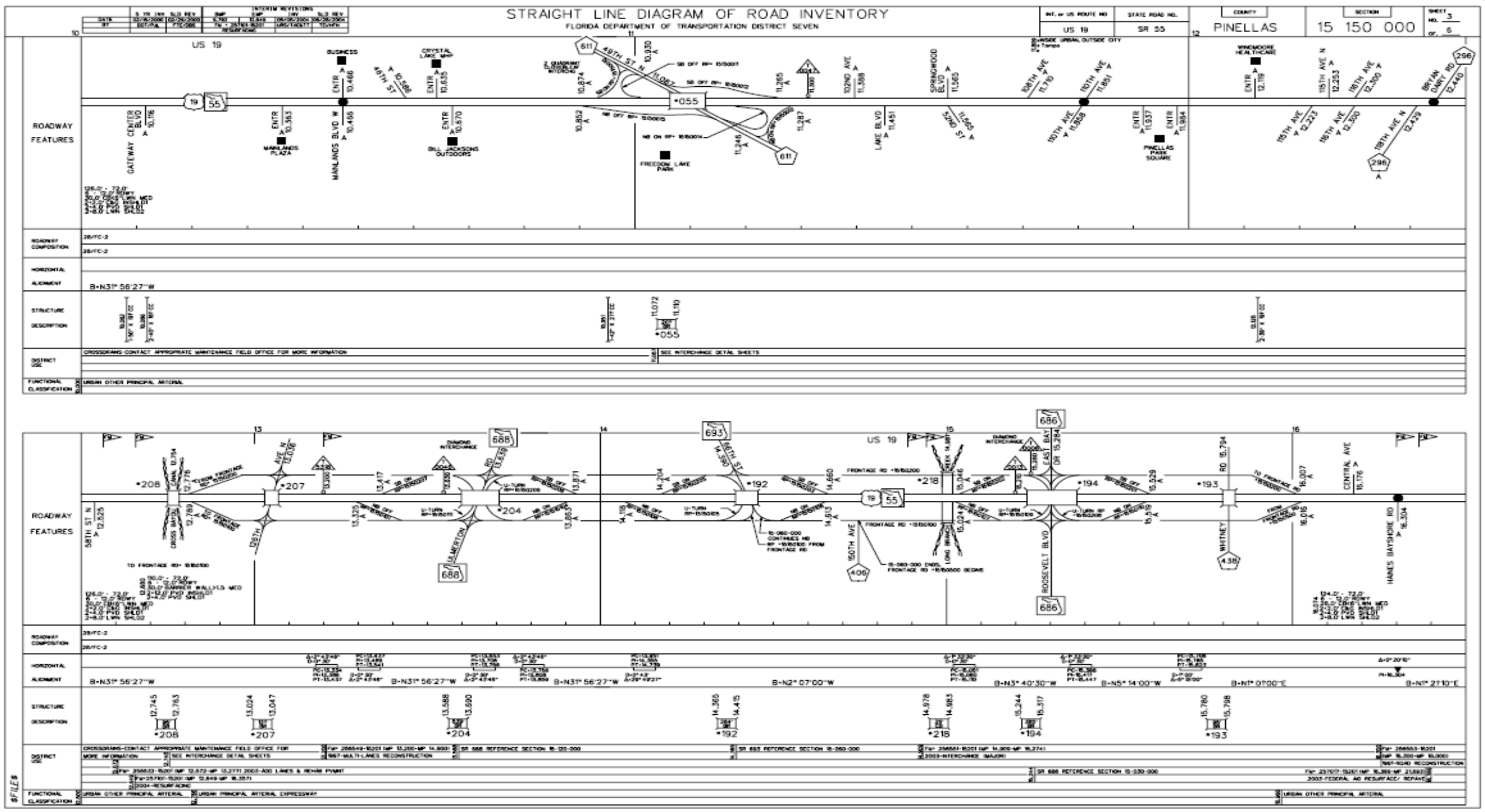

Figure 19: SLD from Milepost 10 to Milepost 15

APPENDIX B. Sample of Access Data Collected for US-19

ROAD ID	Street name	Mile Post	South Bound Driveway Width	South Bound Driveway Use	Median Width	Type Of Median	North Bound Driveway Width	North Bound Driveway Use	Signalized	Approach II - Types
15150000	54 ave	0.87	93.83	Inter	8.22	4 (s)	93.83	Inter	yes	6
15150000		0.91	28.77	G		Div				3
15150000		0.93	30.98	G		Div				3
15150000		0.95	21.87	P C		Div				3
15150000		1	23.35	P C	7.61	4	33.2	Res		1
15150000		1.01			7.61	4	33.2	Res		1
15150000		1.04				Div	30	Res		3
15150000	50 ave	1.1	77.51	Inter	5.37	4	26.15	C		6
15150000		1.12				div	20.31	c		3
15150000		1.15	19.52	Res		Div				3
15150000		1.19	24.02	P C	5.32	4	28.89	C		6
15150000		1.24				Div	17.31	C		3
15150000		1.26				Div	20.2	C		3
15150000		1.29	27.57	P C		Div	28.85	C		7
15150000		1.31	29.1	H	15.74	4	30.05	C		6
15150000		1.34				Div	30.05	C		3
15150000		1.35				Div	23.72	C		3
15150000		1.35	25.3	H		Div				3
15150000	46 ave	1.37	30.18	Inter	7.72	4 (s)	19.68	Inter	yes	6
15150000		1.39	30.05	C		Div	26.57	C		7