DESIGNING TRANSIT ACCESSIBLE COMMUNITIES STUDY

DRAFT WORKING PAPER #2

CATEGORIZATION OF BUS STOPS

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

1.0 Purpose

A key goal of the Designing Transit Accessible Communities (DTAC) project is to develop a toolkit of recommendations to assist local governments in creating safer, more comfortable environments for transit users as they access bus stops by foot or by bicycle. Bus stop categorization was used to establish groupings of bus stop areas for which prototypical pedestrian and bicycle improvement concepts could be developed and recommended in later tasks. This working paper describes the methodology employed to develop categorizations of bus stop areas in local jurisdictions within the Maricopa Association of Governments (MAG) region as part of the MAG *Designing Transit Accessible Communities* (DTAC) study. The study also summarizes findings derived from the evaluation.

This working paper is organized into the following three sections:

Section 2 Previous Studies: summarizes other studies that have attempted to employ similar techniques to categorize or classify transit station or bus stop areas

Section 3 Methodology: describes statistical and spatial analysis techniques used to create bus stop area categories for this study

Section 4 Analysis Results: presents the results of the categorization process, including descriptions of seven bus stop categories defined through the analysis process and selection of case study locations.

2.0 Previous Studies

The literature review found four key studies and plans that identified clusters or typologies as a means of categorizing transit stations/stops. The review of previous studies was an important component of this task to ensure our approach considered the characteristics of the built environment and the transit system in a manner comparable to previous work.

Four studies are described below in terms of the category types developed and methods employed for identifying groupings of built environments and/or transit systems in various U.S. metropolitan regions.

MAG's Sustainable Transportation and Land Use Integration Study

The *Sustainable Transportation and Land Use Integration Study* (ST LUIS) is currently underway at MAG. As part of this planning effort, several working papers and presentations have been developed. In one presentation, the identification of place-types was called out as a possible tool for assisting MAG in "synching up" transportation investments and land development policies. The proposed place-types include consideration of population and employment density, centrality (proximity to core or other centers), employment sectors, and connectivity. In other words, the proposed definition of place-types per the ST LUIS project stem from land use and transportation system characteristics.

Proposed ST LUIS place-types include Suburban, Compact, Transit-Served, and High-Capacity Transit (HCT) Oriented. Compact is defined as 15-30 persons/acre; Transit Served (30-45 persons/acre), and HCT-Oriented as +45 persons/acre. The sequence of slides shown on the following page shows the minimum densities, maximum block sizes, market condition fit, and feasible development prototype for each place-type.

HIERARCHY OF PLACE-TYPES IDENTIFIED DURING THE SUSTAINABLE TRANSPORTATION AND LAND USE INTEGRATION STUDY (ST LUIS)

	COMPACT	TRANSIT SERVED	HCT ORIENTED
1 Establish minimum densities	15 persons/ acre	30 persons/ acre	45 persons/ acre
2 Establish maximum block sizes	4 acre maximum for walkability		
3 Design complete streets	Sidewalks on both sides, safe to cross, welcoming to bicyclists, slow to moderate speed	Sidewalks, easy to cross, welcoming to bicyclists, slow speed	Sidewalks, easy to cross, welcoming to bicyclists, slow speed

	COMPACT	TRANSIT SERVED	HCT ORIENTED
1 Establish minimum densities – Residential	15 persons/ acre	30 persons/ acre	45 persons/ acre
Market condition fit	Widespread	Moderate	Limited
Feasible Development Prototypes	Small lot single family	2-3 story apartments & townhomes	4+ story multifamily

	COMPACT	TRANSIT SERVED	HCT ORIENTED
1 Establish minimum densities – Employment	15 persons/ acre	30 persons/ acre	45 persons/ acre
Market condition fit	Limited – primarily local serving	Central locations	Central locations with lots of jobs
Feasible Development Prototypes	Shopping centers, local downtowns, neighborhood business districts	Intensified business park	Mid-to-high rise offices

TCRP Project B-38: Guidelines for Providing Access to Public Transportation Stations (2011)

These guidelines were prepared through the Transit Cooperative Research Program (TCRP), which is administered by the Transportation Research Board (TRB) of the National Academies. The project was sponsored by the Federal Transit Administration (FTA) in cooperation with the Transit Development Corporation. This report defines fourteen transit station types associated with commuter rail, heavy rail transit (HRT), light rail transit (LRT), and bus rapid transit (BRT). Although the methodology is similar in concept to that required for the DTAC categorization, it varies in one key aspect: its focus is strictly on rail transit and does not address bus transit service.

The station area typology generally considers land use intensity, feeder transit connections, parking availability, and the quality of the pedestrian network. The station catchment area was considered to be the area within 0.5 miles of the station. Eight specific variables were proposed for inclusion in the assessment of station typology. These variables and a brief justification of each are highlighted below:

Housing Density – affects the number of riders living within walking distance of the station.

Scale – measured as average building height in the area surrounding the station, which relates to walkability, density, and activity levels.

Distance from CBD – a measure of station location within the metropolitan area. Stations closer to the core should emphasize pedestrian connections, while commuter connections should focus on parking.

Supporting Transit Network – level of connectivity of the station to other transit service.

Pedestrian/Bike Access – a measure of the completeness and attractiveness of the pedestrian and bicycle networks around the station. Well-formed connections for pedestrians and bicycles are important for assuring successful station access.

Surrounding Land Uses – describes the land use mix in the station area.

Parking Facilities – the level of off-street parking accommodations provided at the station.

Access/Egress – describes the primary role of the station in the transportation system. Some stations are at the "home end" of the journey, while others are at the "destination end."

Accessing Transit, Design Handbook for Florida Bus Passenger Facilities (2008)

This document proposes a hierarchy of bus stop prototypes based on the potential number of passengers or bus routes served. It provides specific design guidelines for each identified bus stop prototype. Proposed prototypes include the following:

On-Line Bus Stops – provide access to transit in a variety of locations, including arterials, collectors, and local streets; may be adjacent to a variety of land uses.

Primary Bus Stops – provide access to more important destinations, where the density of employees or residents results in either high peak-hour use or regular use several times a day. Stops also may serve as a transfer point.

Transit Malls – provide transit access to traditional downtowns and commercial centers and serve as a base for local circulator service, express routes, and other special modes of bus transit. Facility also may serve as the first element in BRT service.

University Transfer Centers – allow students and other riders to connect to multiple regional, local, or campus bus transit systems. Transfer centers are sited to integrate campus circulators, transfer facilities, parking, pedestrian facilities, and bicycle access, including bicycle parking and storage facilities.

Transfer Centers – serve as major nodes in the transit network, connecting various regional and local bus lines, express routes, and circulator services. These facilities are located within major activity centers and designed to ease transferring between bus routes and between bus transit and other travel modes.

Park-and-Ride (P&R) Lots – allow travelers to change their mode of travel from personal automobile to transit. P&R lot design is based on characteristics of the individual sites where they are located. Prototypical P&R facilities include suburban, peripheral, or joint-use park-and-ride lots.

Air-Bus Intermodal Centers – allow for fast, efficient transfers between the bus transit system and airports. Centers generally are housed in permanent facilities and provide a range of passenger amenities. To avoid curb-side congestion, many such centers connect passengers to the airport via grade-separated covered corridors.

2011 MAG Complete Streets Guide

This document proposes a six-step "Complete Streets" planning process that includes: 1) determining the transportation context; 2) identifying current transportation modes and facilities; 3) identifying complete streets gaps; 4) determining other priorities; 5) determining the right-of-way (ROW) and number of lanes; and 6) selecting other complete streets elements.

Step 1 of this planning process is related to the bus stop categorization process employed for the DTAC project. "Prototypical" transportation contexts were established based on land use density and mix, as well as roadway characteristics. The figure to the right shows the categories of land use density defined in the Guide and typical areas with the region that fit the categories.

CATEGORIES OF BUILT ENVIRONMENT AND TRANSPORTATION SYSTEM TYPES FROM 2011 MAG COMPLETE STREETS GUIDE

Summary

In summary, the key studies identified outlined above – in which "categorization" or groupings of built environment or transportation system characteristics was employed – are similar to the process adopted for the DTAC project. Each includes measures of potential demand or activity levels based on land use, as well as transportation system characteristics related to the roadway network or transit service levels. The DTAC study follows a similar approach by classifying bus stop areas using measures of potential travel demand and bus service quality. Details regarding interpretation and application of these measures are described in the next section.

3.0 Methodology

The overall categorization analysis process included the following four general steps:

1. Develop a GIS database of variables describing bus stop areas (*potential demand and transit service quality*) within a one quarter-mile street network buffer area of all bus stops.
2. Perform cluster analysis to identify groupings of bus stop areas.

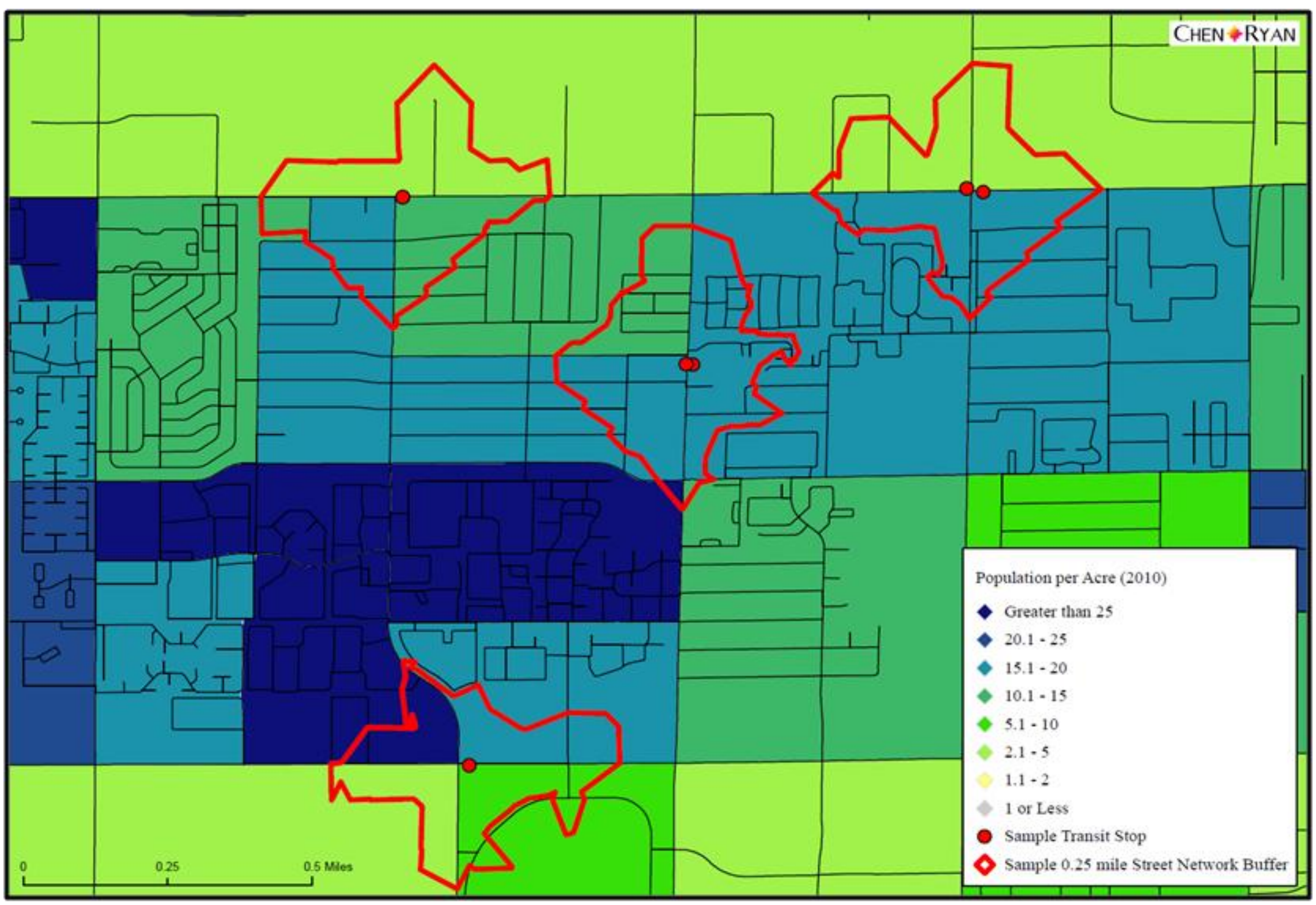
3. Ground-truth cluster analysis results via reviews of aerial imagery available through Google Earth and the conduct of windshield surveys, as appropriate.
4. Propose bus stop locations for conducting case studies.

Steps 1 and 2 are described in the following subsections. Steps 3 and 4 are described in the next section, *Section 4: Analysis Results*.

3.1 Categorization Database Development

The categorization analysis was conducted using variables related to transit, bicycle, and pedestrian demand, as well as bus service quality characteristics. Population and employment variables were obtained from the U.S. Census Bureau; transportation system variables were obtained from MAG.

A one quarter-mile street network buffer was created for each bus stop in the MAG region, and the input variables were calculated for the polygon-defined buffer areas. Population and employment data were apportioned by area to calculate values for the unique buffer polygons. The image below illustrates sample quarter-mile street network buffer areas in the MAG region and their relationship to census block group boundaries, where population density is displayed. Table 1 shows the eight variables used in the categorization analysis.



SAMPLE QUARTER-MILE BUFFER AND POPULATION DENSITY BY CENSUS BLOCK GROUP

Table 1
BUS STOP CATEGORIZATION VARIABLES

Type	Variable	Source
Transit/Bike/Pedestrian Demand	1. 2010 Population per Acre by Census Block Group	American Community Survey US Census
	2. 2009 Employment per Acre by Census Block Group	Longitudinal Employer-Household Dynamics (LEHD) Program US Census
	3. Sum of Population and Employment by Census Block Group	(see above)
	4. Presence of Retail	MAG Land Use
	5. 2010 Density of Zero-Vehicle Households by Census Block Group	American Community Survey US Census
Bus Service Quality	6. Number of Routes per Bus Stop Area	MAG GIS
	7. Location of Bus Stop at Arterial-Arterial Intersection	MAG GIS
	8. Frequency of Bus Service at Bus Stop Area for all Routes	MAG Transit Frequency

Source: Chen Ryan Associates; May 2012.

Table 2 displays descriptive statistics associated with the variables used for bus stop categorization. The values reported in Table 2 reflect quarter-mile street network buffer areas rather than census geography.

Table 2
DESCRIPTIVE STATISTICS OF BUS STOP CATEGORIZATION VARIABLES

Variable	Relevant Area	Minimum	Maximum	Mean (Average)	Standard Deviation
Population Density per Acre	Census Block Group	0	32.1	7.8	4.1
Employment (Jobs) Density per Acre	Census Block Group	0	93.8	5.7	10.1
Presence of Retail	Bus Stop Buffer Area	0	1	0.51	0.49
Density of Zero-Vehicle Households per Acre	Census Block Group	0	4.1	0.32	0.39
Density of Population and Employment (Jobs)	Census Block Group	0	101.2	13.5	10.50
Number of Routes	Bus Stop	1	12	1.2	0.65
Presence at Arterial-Arterial Intersection	Bus Stop	0	1	0.23	0.42
Frequency of Bus Service*	Bus Stop	1	4	3.3	0.84

*Note: For the purposes of this study, high-frequency transit service is considered to operate on a headway of 20 minutes or less. Transit service frequency was divided into four categories, as follows: 1) bus stops with multiple all-day, high-frequency routes; 2) bus stops along a single all-day, high-frequency route; 3) bus stops along routes that have high-frequency service during peak commute periods; and 4) bus stops that have no high-frequency service.

Source: Chen Ryan Associates; May 2012.

Figures 1 through 8 display each of the categorization input variables for the MAG region. A summary interpretation of each figure follows.

Figure 1 shows the density of the 2010 population by census block group. As shown in Table 2, population density in the MAG region ranges from 0 to 32.1 persons per acre by census block group, with a mean density of 7.8 persons per acre. The eight data ranges in Figure 1 were defined using the Natural Breaks classification method in ArcEditor 10.[1]

Figure 2 shows the density of 2009 employment by census block group. Employment density in the MAG region ranges from 0 to 93.8 jobs per acre, with a mean density of 5.7 jobs per acre. The eight data ranges in Figure 2 were defined using the Natural Breaks classification method in ArcEditor 10.

Figure 3 shows the presence of retail land use across the MAG region in 2009. Presence of retail in the quarter-mile buffer was included as a dichotomous variable in the cluster analysis, i.e., as "yes" (1) or "no" (0) retail within the buffer.

Figure 4 shows the density of zero-vehicle households (HHs) in 2010 by census block group. The density of zero-vehicle households in the MAG region ranges from 0 to 4.1 HHs per acre, with a mean density of 0.32 HHs per acre. A value of zero for this variable means that all households in the census block group have at least one vehicle. The eight data ranges in Figure 2 were defined using the Natural Breaks classification method in ArcEditor 10.

Figure 5 shows the density of population and employment by census block group. This variable was used to reflect transit "trip end" potential. In other words, the location of a person's residence or work place is a good approximation of the majority of potential transit trip origins and destinations that might occur across the region. The density of the sum of population and employment ranges from 0 to about 101 persons and jobs per acre by census block group. The seven data ranges in Figure 5 were defined using the Natural Breaks classification method in ArcEditor 10.

Figure 6 shows the number of routes by bus stop across the MAG region. This variable is a measure of transit service quality, assuming that a greater number of routes serving a given bus stop would provide higher levels of system connectivity. The number of routes by bus stop ranges from 1 to 12 routes, with a mean of 1.2.

Figure 7 shows those bus stops across the MAG region situated at arterial-arterial intersection locations. This was used as a measure of the quality of bus transit service. Like the presence of retail land use, the presence of a route or routes at an arterial-arterial intersection was included as a dichotomous variable in the cluster analysis, i.e., as "yes" (1) or "no" (0) route serving the intersection.

Figure 8 shows the frequency of service by bus stop. For purposes of this study, high-frequency bus service was defined as an operating headway of 20 minute or less at the bus stop. Routes passing bus stops were classified into four operational categories, including: Multiple All Day, High-Frequency Routes; a Single All-Day, High-Frequency Routes; High Frequency Service during the Peak Periods Only; and No High-Frequency Routes.

[1] The Natural Breaks classification methods involves "…manual data classification that seeks to partition data into classes based on natural groups in the data distribution. Natural breaks occur in the histogram at the low points of valleys. Breaks are assigned in the order of the size of the valleys, with the largest valley being assigned the first natural break (from GIS Dictionary at Esri Web site)." In general, this method should maximize the between-class differences and minimize the within-class differences.

Figure 1
2010 Population Density by Census Block Group

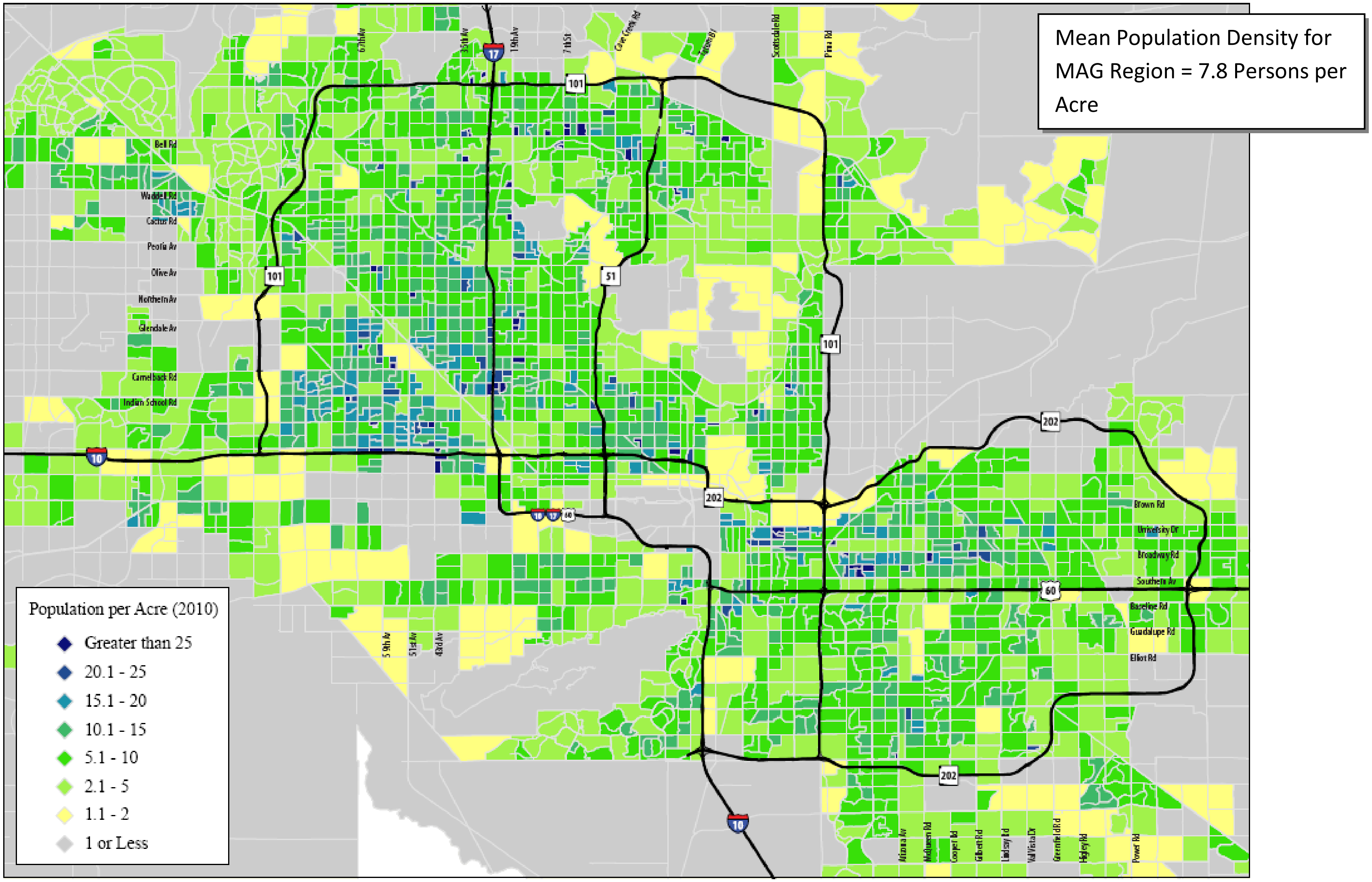
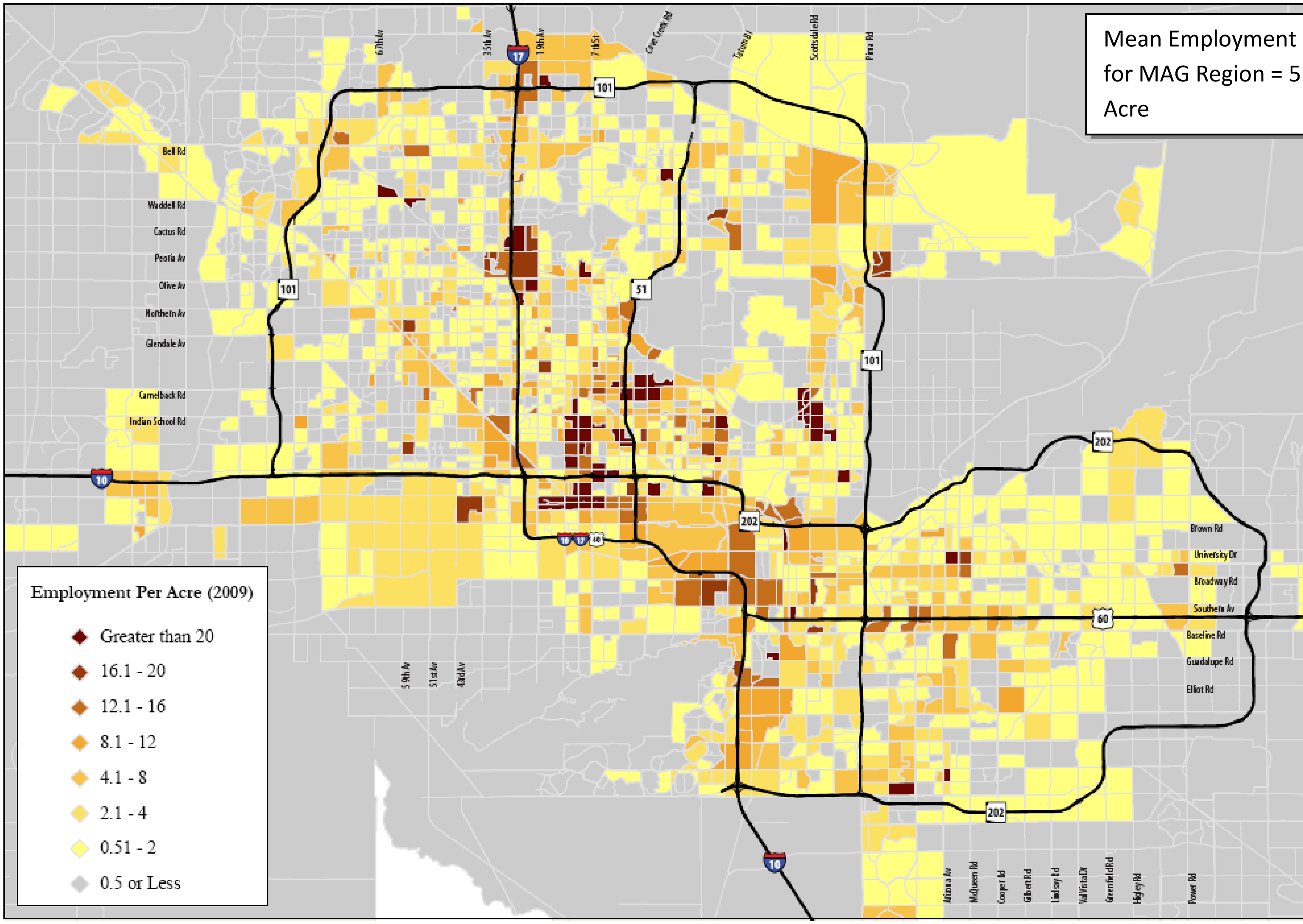
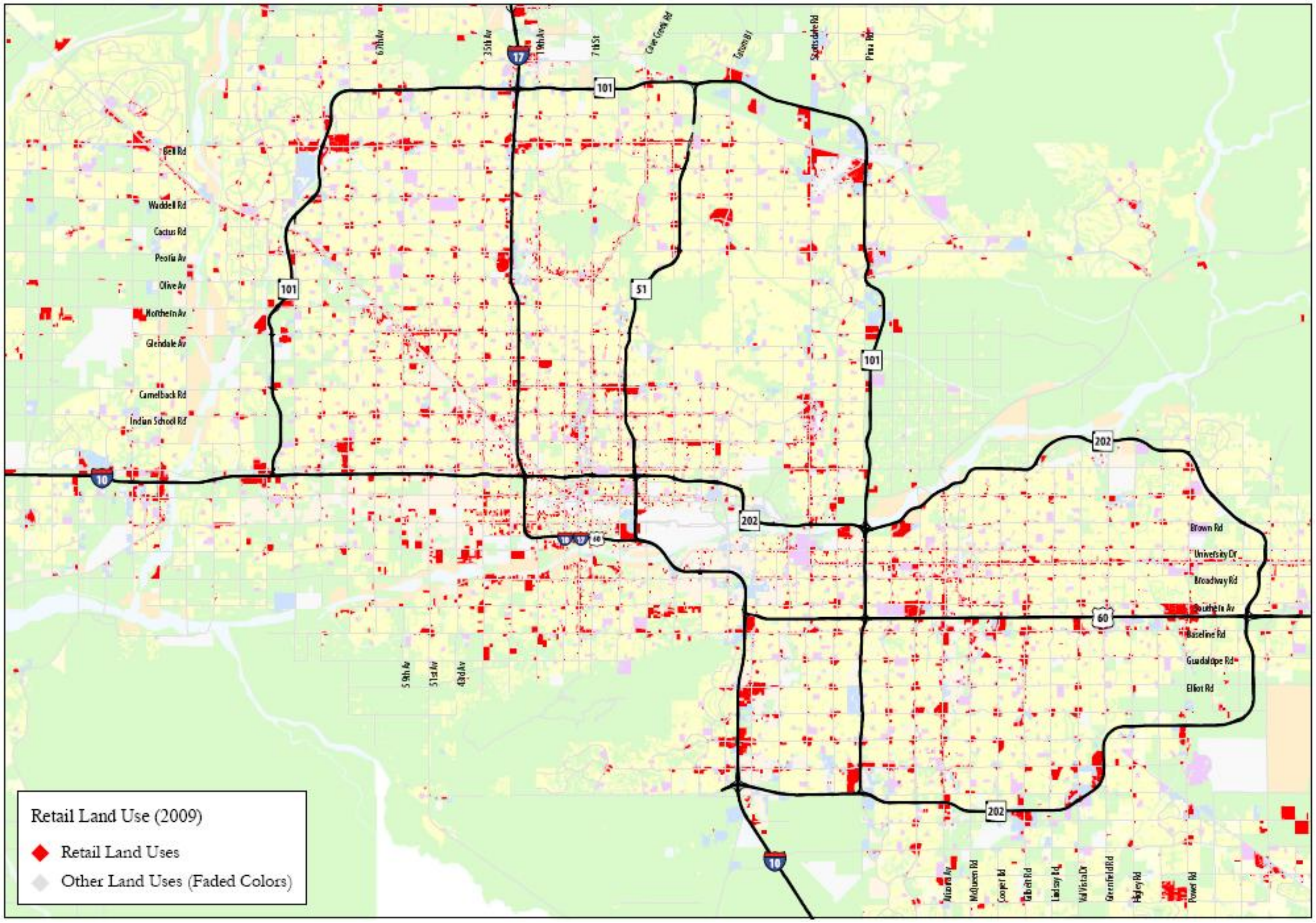


Figure 2
2009 Employment Density by Census Block Group



Mean Employment Density for MAG Region = 5.7 Jobs per Acre

Figure 3
2009 RETAIL LAND USE



July, 2012

Figure 4
2010 DENSITY OF ZERO-VEHICLE HOUSEHOLDS BY CENSUS BLOCK GROUP

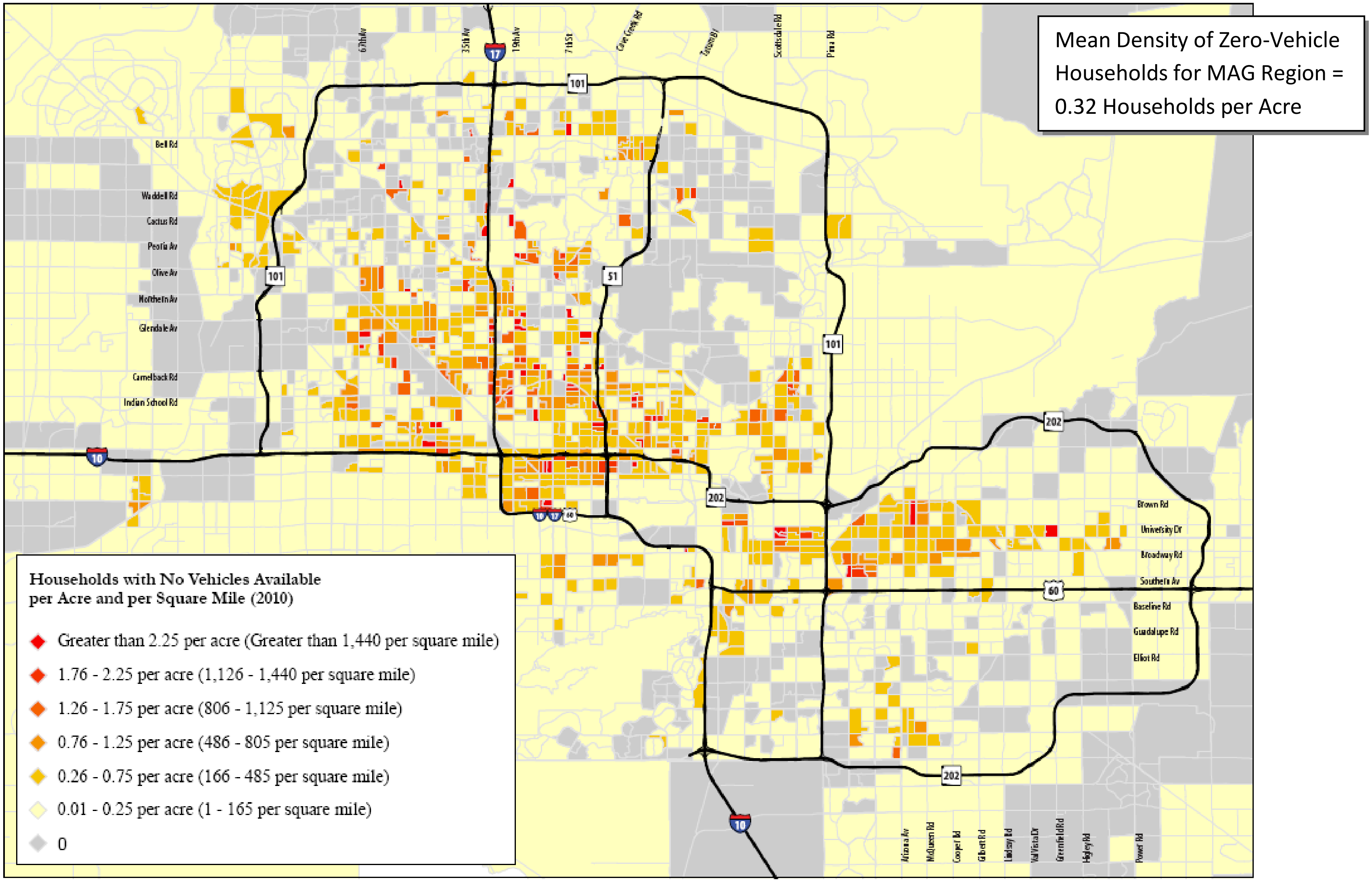


Figure 5

TOTAL SUM OF POPULATION AND EMPLOYMENT BY CENSUS BLOCK GROUP

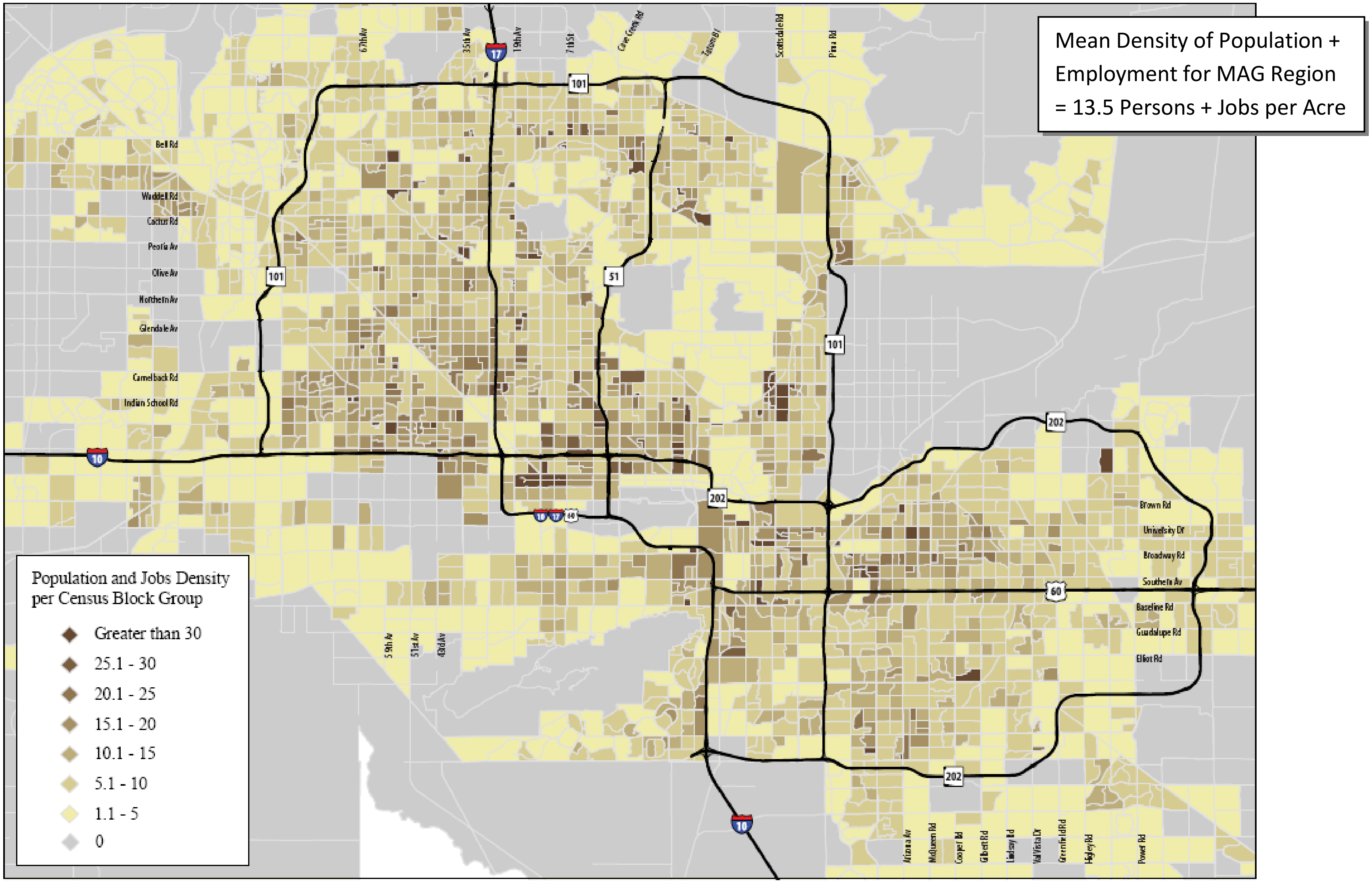


Figure 6
NUMBER OF ROUTES PER BUS STOP AREA

Mean Number of Bus Routes per Stop for MAG Region = 1.2 Routes per Stop

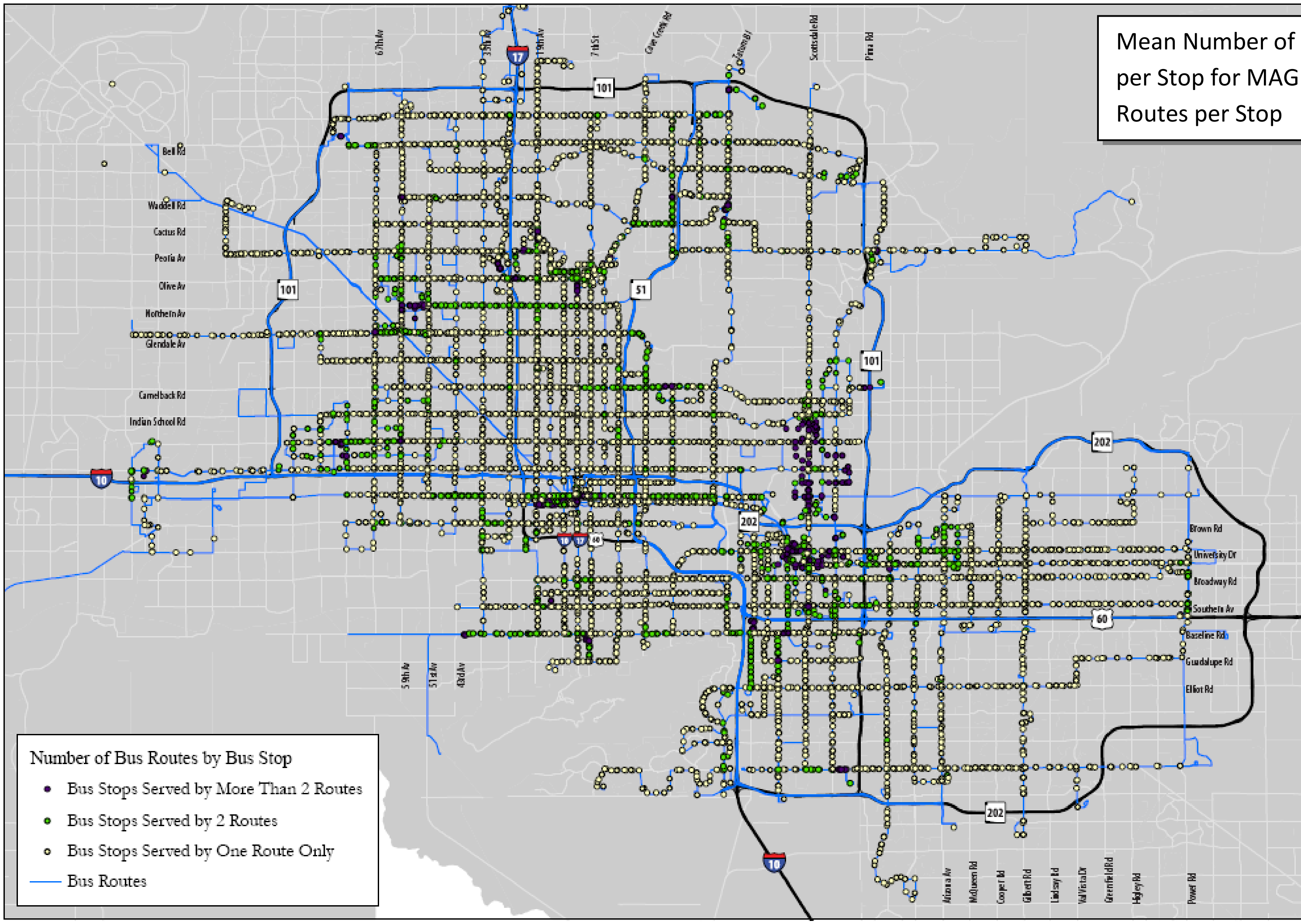


Figure 7
LOCATIONS OF BUS STOP AREAS AT ARTERIAL-ARTERIAL INTERSECTIONS

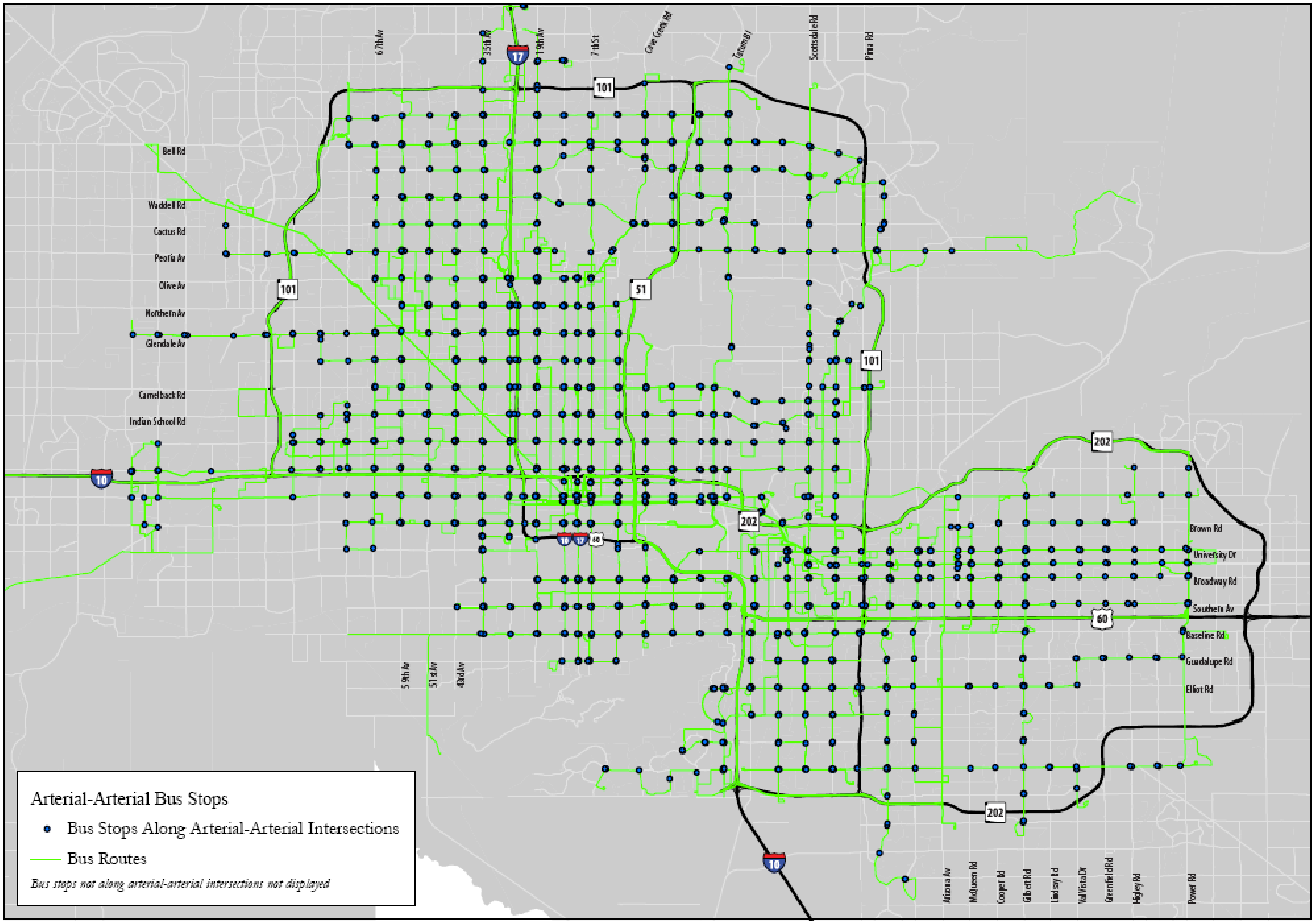
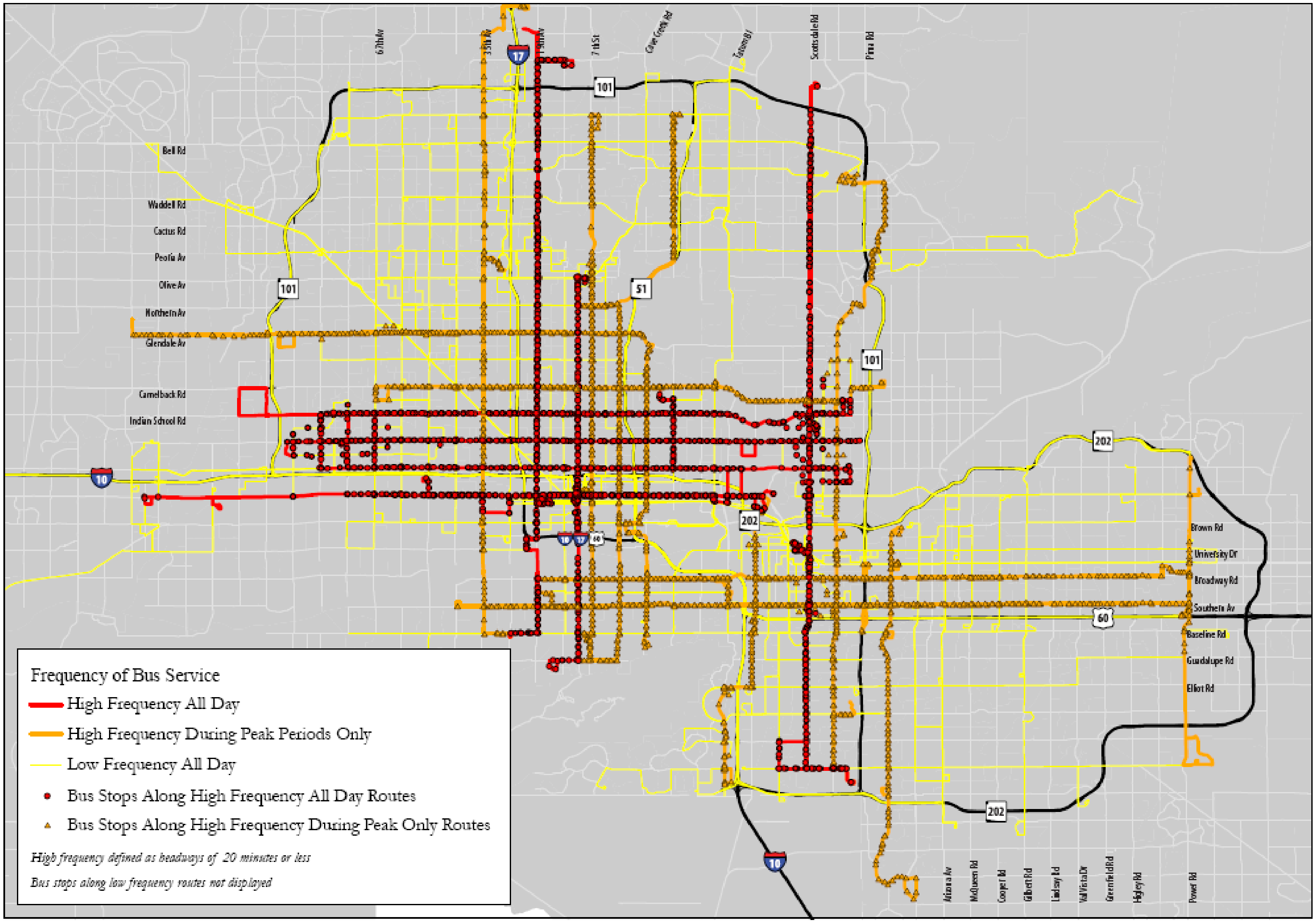


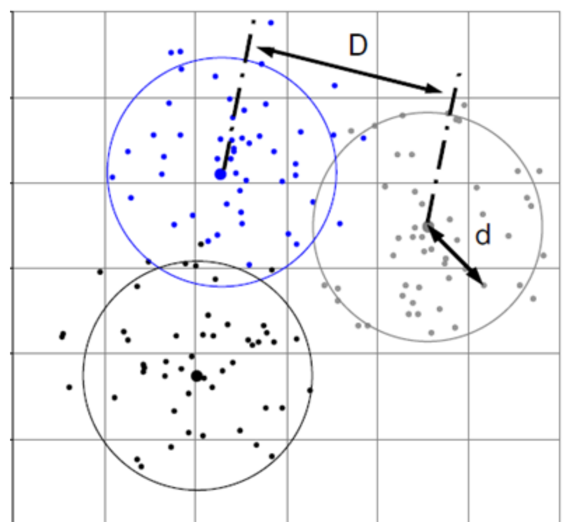
Figure 8
FREQUENCY OF BUS TRANSIT ROUTE SERVICE AT BUS STOP AREAS



3.2 Cluster Analysis

Given the broad geographic scope and the sheer number of locations considered (over 5,000 bus stop areas across the MAG region), a statistical cluster analysis was considered to be the most appropriate method for identifying categories of bus stop areas. Therefore, the consultant team decided to employ a technique that was largely automated and objective. The readily available statistical software package called Statistical Package for the Social Sciences (SPSS v.19) was used to perform the cluster analyses. The cluster analysis routine is exploratory in nature, designed to reveal natural groupings (or clusters) within a collection of observed phenomena, i.e., data or a database. It has been described as a technique for "classifying a mountain of data into manageable, meaningful piles" (IBM, 2010. *IBM SPSS Statistic Base 19*). The analysis technique examines the inter-relationships between input variables, defines appropriate groups (clustering), and assigns particular pieces of the data mountain to the groups (classification). The result is clusters of observations or cases, in this case transit stops. The SPSS analysis process assists in this effort by where similarity within groups is maximized, while similarity between groups is minimized. It supports organization of the data into groups based on combinations of the input variables. The method requires standardizing all input variables so their values are on the same scale and equally weighted, then calculating the difference between each of the cases for all variables. Cases with smaller differences are grouped into clusters.

The SPSS cluster analysis tool considers the user-specified input variables, then provides several key outputs that support an assessment of the "cluster model" goodness-of-fit or strength. These outputs include the number of clusters, the number of cases in each cluster, and a "silhouette measure" that reflects the overall cohesion and separation of the particular cluster model. The silhouette measure ranges from 0 to 1, with 1 indicating strong cohesion within clusters and separation between clusters.



Cluster Analysis Technique:
Define clusters where distance "D" is maximized and distance "d" is minimized.

The MAG DTAC study team was interested in developing approximately five to 10 categories of bus stop areas, so the number of clusters was a relevant output for consideration. A systematic approach to the cluster analysis was adopted, entailing separate examination of the demand-related variables and bus service characteristics variable (refer to Table 1). Based on outputs from the initial cluster model runs, subsequent combinations of demand and service quality variables were examined with the goal of achieving a workable number of clusters (i.e., five to 10 clusters) and a strong silhouette measure. In other words, the cluster analysis process was structured around the following three questions:

Is clustering exhibited in the *demand* measures?

Is clustering exhibited in *transit service quality* measures?

Are clusters demonstrated using *both* demand and service quality measures?

Table 3 displays results of cluster model runs performed with demand-related variables only. Model Run #1 includes population density, employment density, zero-vehicle household (HH) density, and retail. Model Run #2 is the same as #1, but retail is excluded. Model Run #3 includes the sum of population and employment, rather than individual measures of these variables, along with zero-vehicle household density. Model Run #4 adds retail to the variables of Model Run #3. Appendix A includes four maps for Model Runs #1 – #4, reflecting the assignment of each bus stop area to a cluster.

Table 3
DEMAND-RELATED CLUSTER MODEL RUNS (#1 – #4)

Run #	Pop Density	Emp Density	Zero Vehicle HH Density	Retail	Pop + Emp Density	No. of Routes	Freq. of Service	Arterial - Arterial
	Demand					Transit Service		
#1	√	√	√	√				
#2	√	√	√					
#3			√		√			
#4			√	√	√			

Source: Chen Ryan Associates; May 2012.

Model Run #5 was performed with the transit-related variables only (Table 4). Model Run #5 includes the number of bus routes by bus stop, the frequency of service associated with each bus stop, and the presence of the bus stop at an arterial-arterial intersection. Appendix B includes a map of each bus stop area and its cluster assignment under Model Run #5.

Table 4
TRANSIT SERVICE-RELATED CLUSTER MODEL RUN (#5)

Run #	Pop Density	Emp Density	Zero Vehicle HH Density	Retail	Pop + Emp Density	No. of Routes	Freq. of Service	Arterial - Arterial
	Demand					Transit Service		
#5						√	√	√

Source: Chen Ryan Associates; May 2012.

Table 5 displays Model Runs #1 to #5, as presented above plus Model Runs #6 – #10. These five subsequent model runs incorporated combinations of travel demand and transit system service variables as input measures for the SPSS software. Model Run #6 included the most variables or any model run: zero-vehicle households, retail, the sum of population and employment, and the three transit system service variables. Model Run #7 was similar to #6; however, the input identifying arterial-arterial intersection bus stops was removed. Model Runs #8 through #10 incorporate fewer demand and transit system service variables in combination. Appendix C contains five maps of the bus stop areas and the cluster assignments for these Model Runs #6 – # 10.

Table 5 shows how each model run performed relative to two key factors used to assess the reliability of cluster analysis output, namely: the number of clusters and the silhouette measure. Number of clusters provides an indication of how many natural or meaningful groupings can be identified within the database. The MAG DTAC study team was looking for approximately five to 10 clusters or categories of bus stops to support development of a reasonable number of prototypes to characterize the different bus stop areas. The silhouette measure, as calculated

Table 5
Demand, Transit System Service, and Combined Variables for Cluster Model Runs #1 - #10 with Number of Clusters and Silhouette Measure

Run #	Pop Den	Emp Den	Zero Veh HH Den	Retail	Pop + Emp Den	No. of Routes	Freq.	Art - Art	Number of Clusters	Silhouette Measure (Cohesion & Separation)
	Demand					Transit System			Cluster Assessment	
#1	√	√	√	√					2	Good (0.7)
#2	√	√	√						2	Fair (0.5)
#3			√		√				2	Good (0.7)
#4			√	√	√				3	Good (0.8)
#5						√	√	√	10	Good (0.8)
#6			√	√	√	√	√	√	2	Fair (0.5)
#7			√	√	√	√	√		5	Fair (0.4)
#8			√		√		√		3	Good (0.7)
#9					√		√		4	Good (0.8)
#10				√	√		√		**7**	**Very Good (0.9)**

Source: Chen Ryan Associates; May 2012.

with SPSS, provides an indication of the cohesion or strength within groupings and the degree of separation between groupings, e.g., bus stops A-D in Group 1 are very similar and differ notably from bus stops H-M in Group 5. The value of the silhouette measure ranges from 0 to 1: '1' represents perfect clustering and '0' represents no clustering.

Table 5 presents these output measures as a way to support the assessment of each model run and determine which provides the most reliable representation of similarities and differences among and between groups of bus stops. The results of Model Runs #1 - #3 and #6 were not ideal, producing only two meaningful clusters, although Model Runs #1 and #3 do have Good silhouette measures of 0.7. Models Runs #4, #8, and #9, while having Good silhouette measures, also were considered in adequate, as these runs produced fewer than five meaningful clusters. Model Run #7 provided five clusters, which satisfied the DTAC study team's requirement for five to 10 clusters; however, only a Fair silhouette measure of 0.4 was achieved. For this run, one of the transit system service variables – presence of the bus stop area at an arterial-arterial intersection – was removed, as it only has two values (i.e., "yes" or "no") which could, in effect, swamp the clustering results.

As shown in Table 5, a total of ten model runs were performed to identify two runs that provided both a desirable number of clusters and a high silhouette measure. Those model runs are Model Runs #5 and #10. Model Run #5 provided 10 clusters, which satisfied the DTAC study team's requirement for five to 10 clusters, and a Good silhouette measure of 0.8 was achieved. The tenth model run, which includes retail, the sum of population and employment, and transit service frequency, produced seven-clusters with a silhouette measure of 0.9. This model run proved to be have strongest silhouette measure of 0.9 and satisfied the DTAC study team's requirement for five to 10 clusters. Therefore, Model Run #10 was selected as the cluster model for use in defining transit bus stop area categories.

4.0 Analysis Results

The purpose of this section is to present the final steps of the analysis process followed to define bus stop categories, i.e., prototypical bus stop areas. These last steps included naming bus stop categories, ground-truthing the bus stop categories, and selecting bus stop locations from each category to serve as the focus of case studies in subsequent tasks.

4.1 Naming Bus Stop Categories

The cluster analysis results presented in Section 3.0 indicate categorization of bus stop areas would best be based on Model Run #10 and the three variables incorporated in the run, namely: Retail Land Use, Density of Population and Employment, and Frequency of Transit Service. The seven clusters derived through Model Run #10 provided the basis for identifying seven categories of bus stop areas. Table 6 identifies the seven bus stop categories, or bus stop area prototypes, presenting the prototypes in a hierarchy that reflects the continuum from urban to suburban service areas. The table also identifies the defining characteristics of each category relative to the three variables used for Model Run #10. A brief interpretation of each of the seven bus stop area categories is provided below.

1. **Metropolitan Core:** Bus stop areas have some retail land use, along with very high employment (ranging from 0.5 jobs per acre to 94 jobs per acre) and multiple all-day, high-frequency transit routes. Four percent of the bus stop areas across the MAG region fall into this category.
2. **Urban Transit Corridor:** Bus stop areas have retail land uses, at least one all-day, high-frequency transit route service, and a relatively high density of population and employment (ranging from 2 persons + jobs per acre to 36 persons + jobs per acre). This category accounts for 12 percent of all bus stop areas.
3. **Suburban Transit Corridor:** Bus stop areas in this category are similar to those related to the Urban Transit Corridor, except there is no retail land use present, and the mean density of population and employment is lower than for a Urban Transit Corridor (12 persons + jobs per acre versus 13 persons + jobs per acre). Eight percent of all bus stop areas fall into this category.
4. **Suburban Peak Hour Transit Corridor:** Bus stop areas have retail land use present, high-frequency transit route service confined to peak periods only, and high population and employment density. This category accounts for 15 percent of all bus stop areas in the MAG region.
5. **Suburban Transit Connectors:** Bus stop areas in this category have retail land use present and medium population and employment density; however, there are no high-frequency transit routes serving these locations. This type of bus stop area accounts for the second highest share – 22 percent – of all bus stop areas in the MAG region.

Table 6
HIERARCHY OF BUS STOP AREA CATEGORIES

Category Ranking	Category Name	Defining Characteristics	Number of Stops	Percent of Total
#1	Metropolitan Core	Some Retail; Very High Employment; Multiple High Frequency Transit	223	4%
#2	Urban Transit Corridors	Retail; High Frequency Transit; High Population and Employment	675	12%
#3	Suburban Transit Corridors	No Retail; High Frequency Transit; Medium Population and Employment	456	8%
#4	Suburban Peak Hour Transit Corridors	Retail; Limited High Frequency Transit; High Population and Employment	865	15%
#5	Suburban Transit Connectors	Retail; No High Frequency Transit; Medium Population and Employment	1,302	22%
#6	Low Suburban Peak Hour Transit Corridors	No Retail; Limited High Frequency Transit; Low Population and Employment	653	11%
#7	Low Suburban Transit Connectors	No Retail; No High Frequency Transit; Low Population and Employment	1,648	28%

Source: Chen Ryan Associates; May 2012.

6. **Low Suburban Peak Hour Transit Corridor:** Bus stop areas have no retail land use present, high-frequency transit route service limited to the peak period, and, importantly, low population and employment density (ranging from 0.5 to 23 persons + jobs per acre, with a mean value of 11). Eleven percent of all bus stop areas fall into this bus stop area category.
7. **Low Suburban Transit Connector:** Bus stop areas have no retail land use present, no high-frequency transit route service, and low population and employment density. This category is the most common type of bus stop area, accounting for the greatest share of bus stop areas in the MAG region. Twenty-eight percent, or 1,648 bus stop areas fall within this category.

Table 7 provides more specific details regarding the characteristics of each bus stop area prototype relative to the three variables utilized for Model Run #10. The right-most column of Table 7 reiterates the defining characteristics that differentiate the seven clusters and reflect the urban to suburban continuum related to the locations of the bus stop areas.

Figure 9 displays all bus stops across the MAG region classified into their respective category.

Figures 10 through 16 display each of the bus stop categories individually.

Table 7
Summary of Categories Resulting from Cluster Analysis

Proposed Category Hierarchy and Name	Total Count of Bus Stop Areas	Retail Land Use	Count	Range of Population + Employment Density	Mean	Range of Population Density	Mean	Range of Employment Density	Mean	Transit Route Frequency	Count	Defining Characteristics
#1 Metropolitan Core	223 (4%)	Yes	78 (35%)	8-101	48	3-17	8	0.5-94	41	Multiple High-Frequency	81 (36%)	• Some Retail Land Use • Multiple High-Frequency Transit Route Service • Very High Employment Density
		No	155 (65%)							One All-Day High-Frequency	83 (37%)	
										Peak Hour Only	41 (19%)	
										No High-Frequency	18 (8%)	
#2 Urban Transit Corridor	675 (12%)	Yes	675 (100%)	2-36	15	0.5-29	9	0-33	6	One All-Day High-Frequency	675	• Retail Land Use • High-Frequency Transit Route Service • High Population and Employment Density
#3 Suburban Transit Corridor	456 (8%)	No	456 (100%)	2-40	12	0.5-31	8	0-31	5	One All-Day High-Frequency	456	• No Retail Land Use • High-Frequency Transit Route Service • Medium Population and Employment Density
#4 Suburban Peak Hour Transit Corridor	865 (15%)	Yes	865 (100%)	1-37	13	0.5-23	8	0.1-34	5	Peak Hour Only	865	• Retail Land Use • Limited High-Frequency Transit Route Service • High Population and Employment Density
#5 Suburban Transit Connector	1302 (22%)	Yes	1302 (100%)	1-44	13	0.5-32	8	0.2-39	5	No High-Frequency	1302	• Retail Land Use • No High-Frequency Transit Route Service • Medium Population and Employment Density
#6 Low Suburban Peak Hour Transit Corridor	653 (11%)	No	653 (100%)	0.5-40	11	0.5-23	7	0-35	3	Peak Hour Only	653	• No Retail Land Use • Limited High-Frequency Transit Route Service • Low Population and Employment Density
#7 Low Suburban Transit Connector	1648 (28%)	No	1648 (100%)	0.5-38	11	0-21	8	0-33	3	No High-Frequency	1648	• No Retail Land Use • No High Frequency Transit Route Service • Low Population and Employment Density

TOTAL Bus Stop Areas Analyzed: 5,822 (100%)

Source: Chen Ryan Associates; May 2012.

Figure 9
SUMMARY OF BUS STOP CATEGORIZATION PROCESS

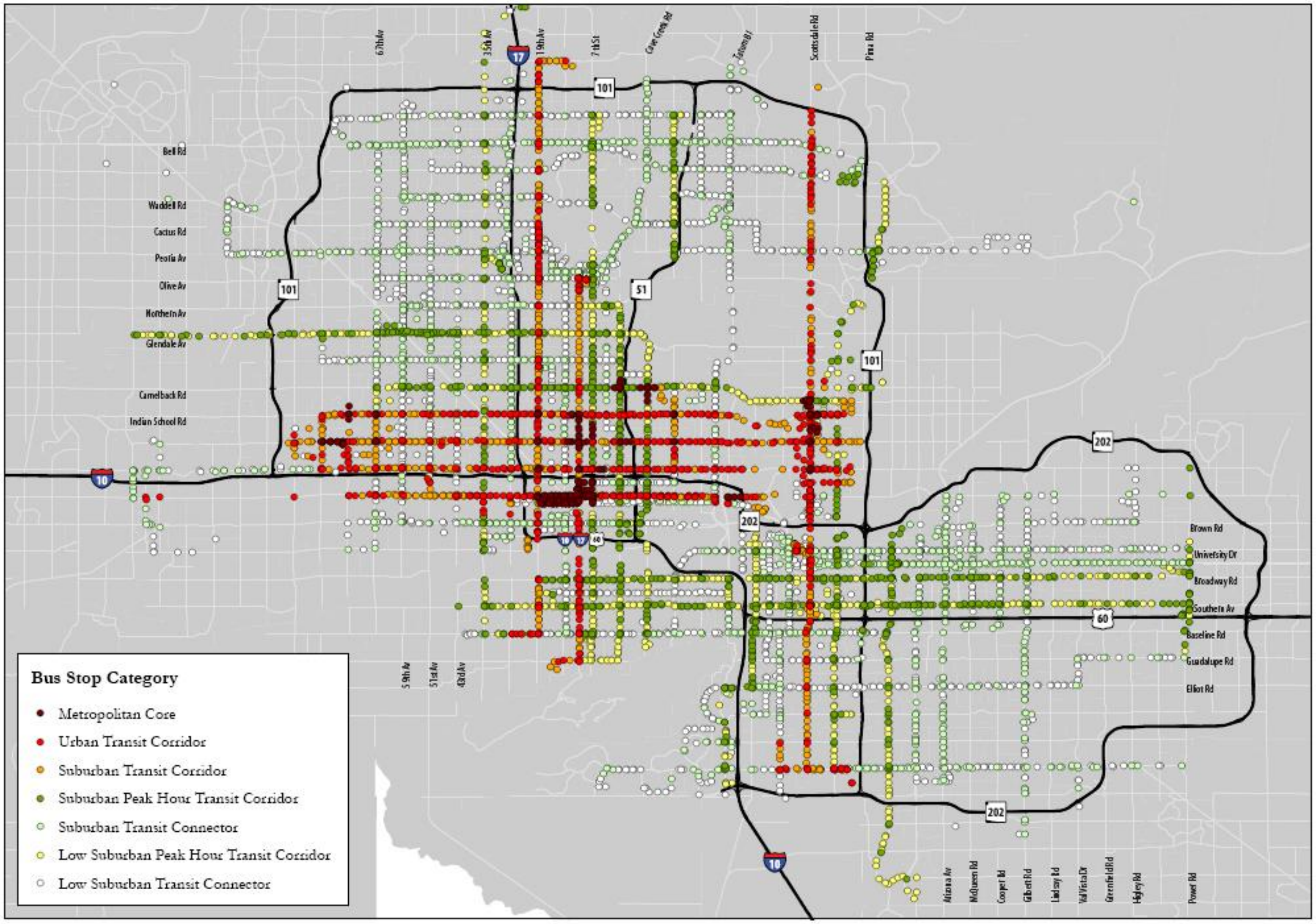
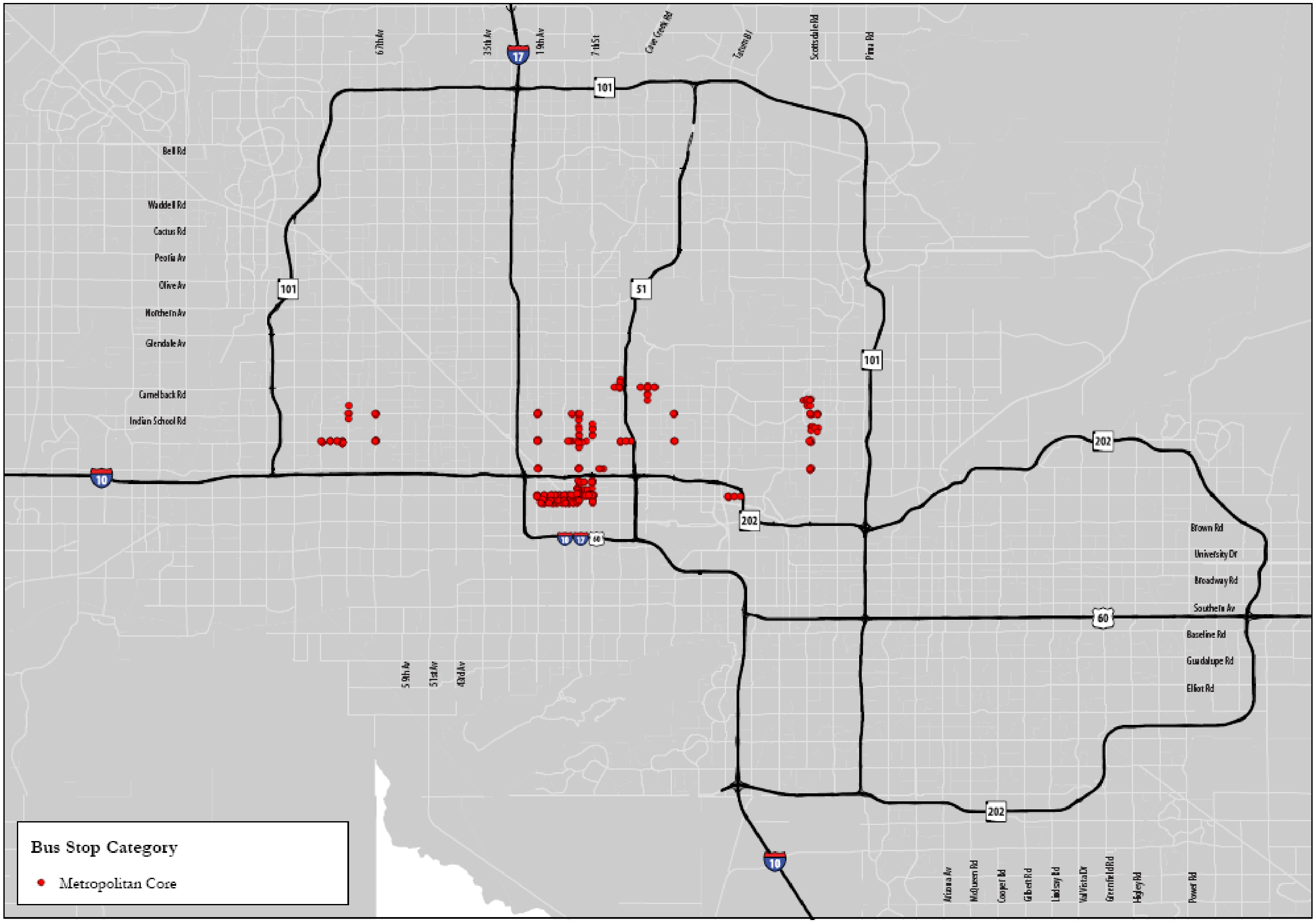


Figure 10
Bus Stop Categorization – Metropolitan Core



July, 2012

Figure 11

Bus Stop Categorization – Urban Transit Corridor

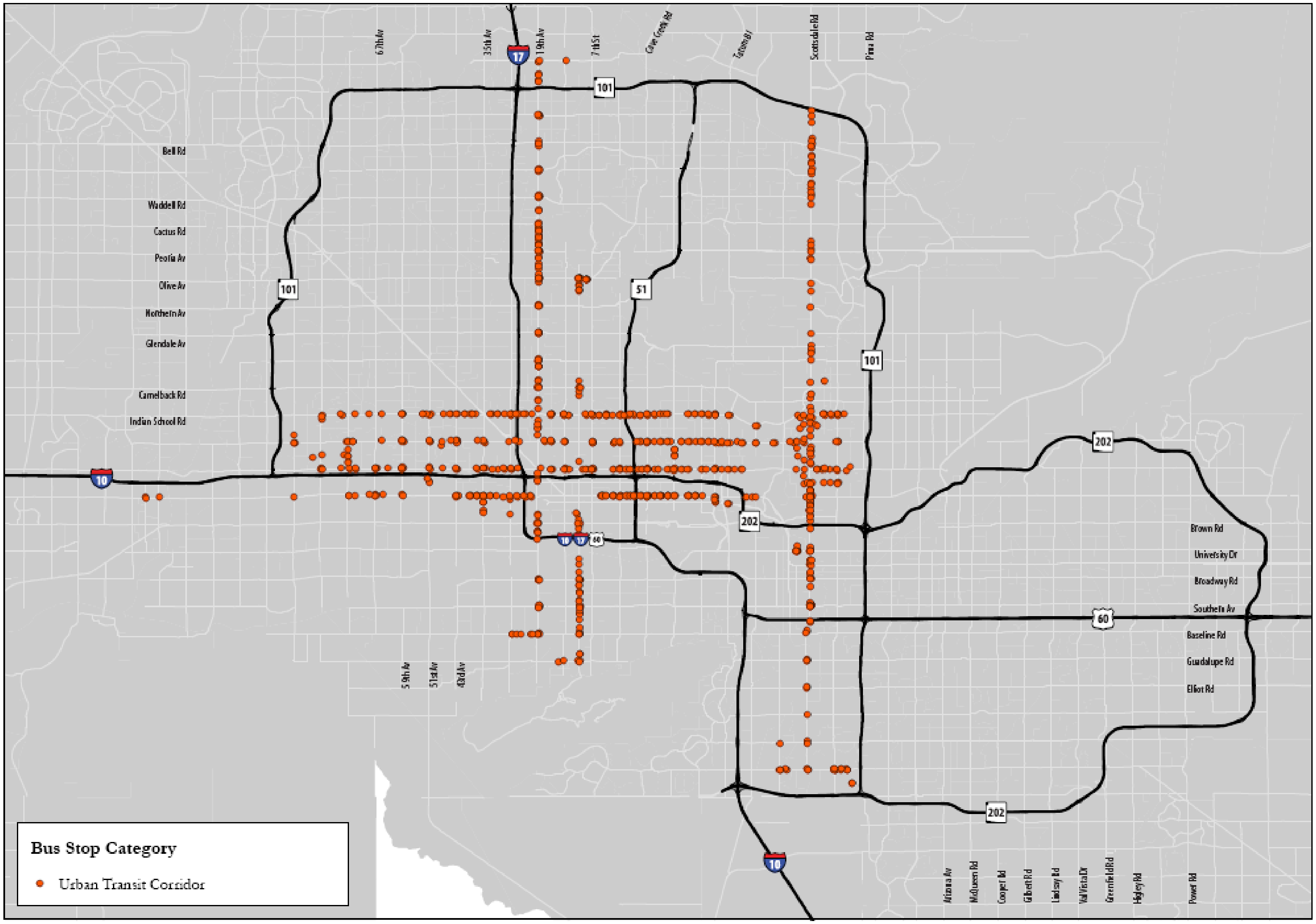


Figure 12
BUS STOP CATEGORIZATION – SUBURBAN TRANSIT CORRIDOR

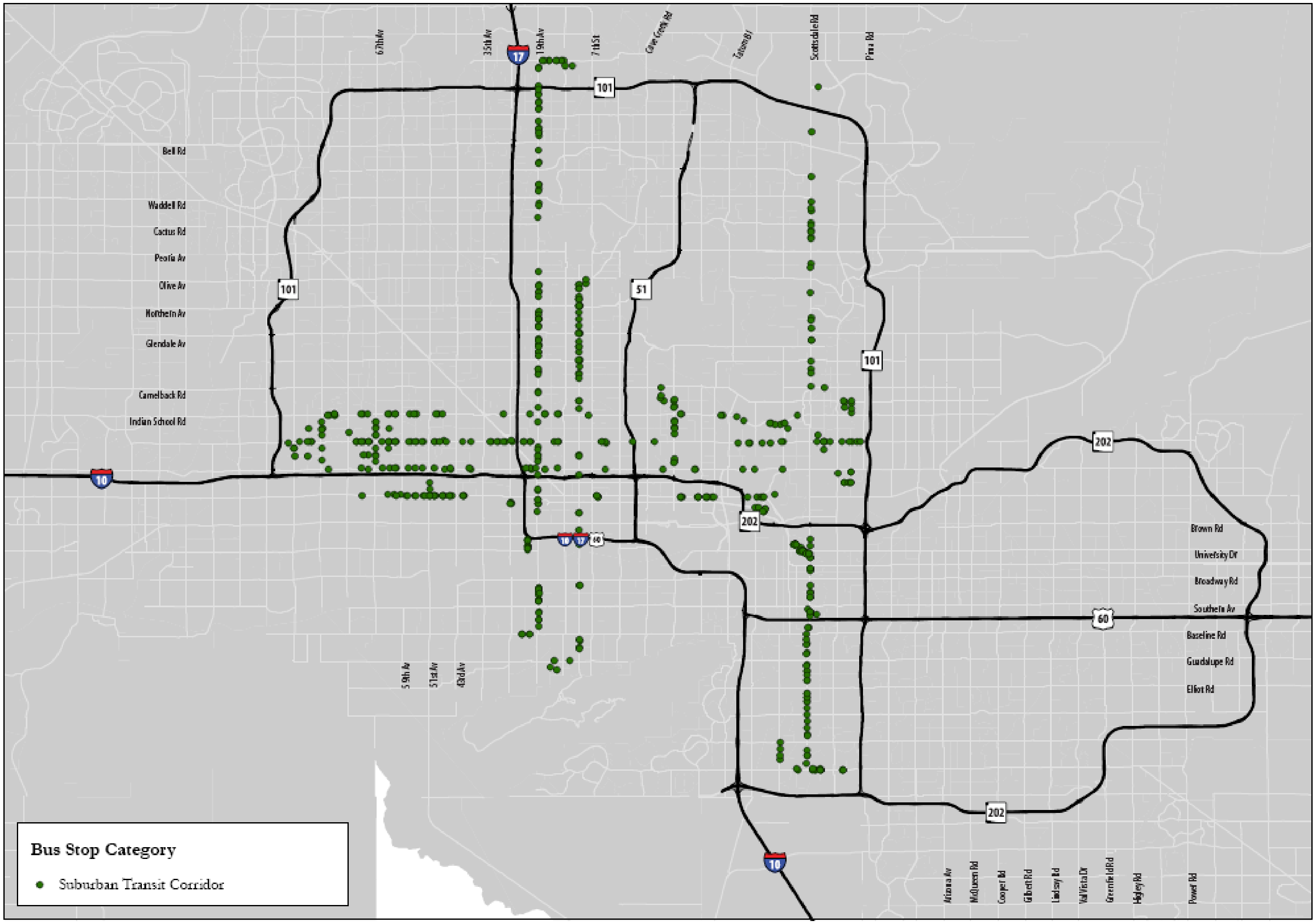


Figure 13

BUS STOP CATEGORIZATION – SUBURBAN PEAK HOUR TRANSIT CORRIDOR

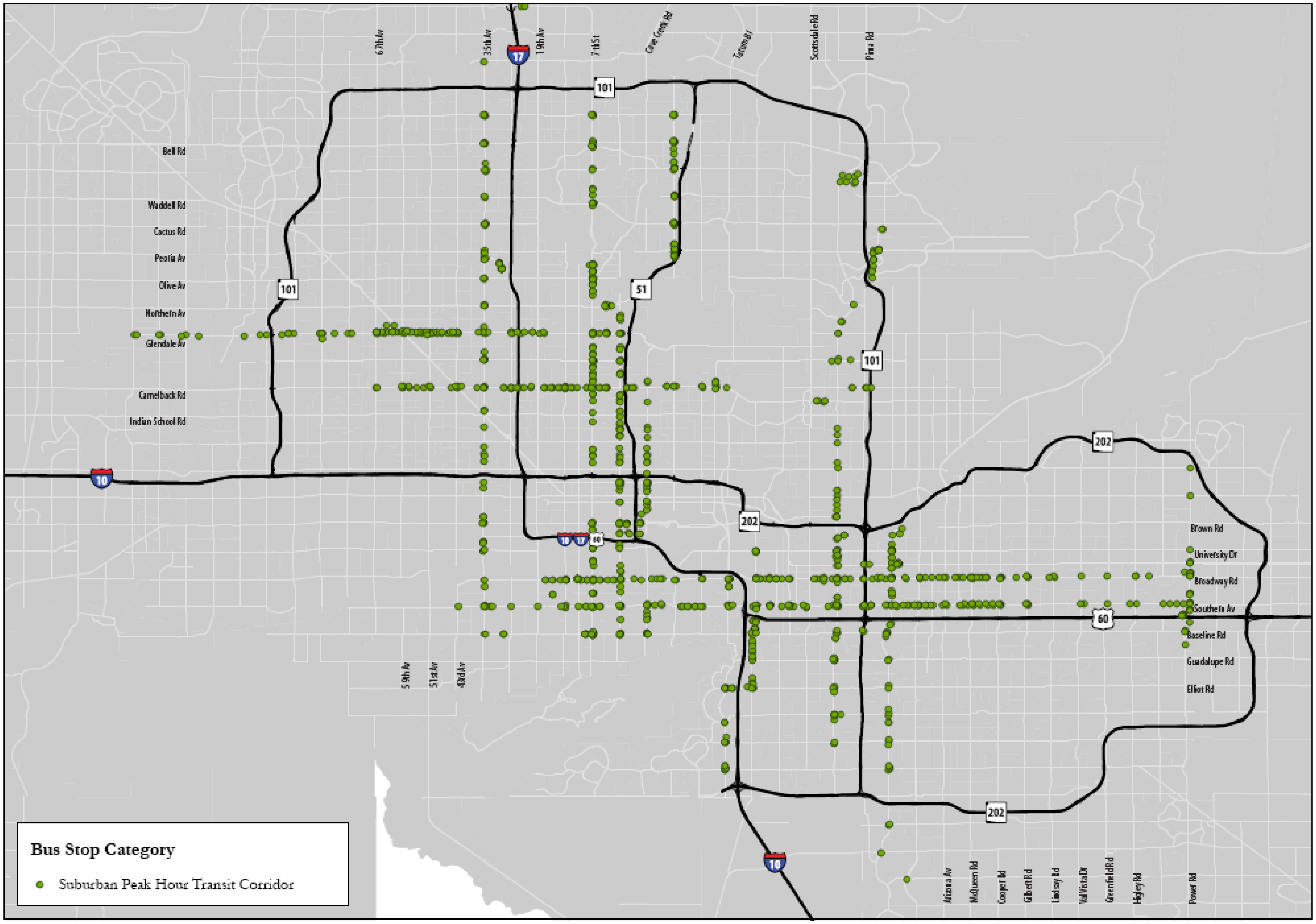


Figure 14

BUS STOP CATEGORIZATION – SUBURBAN TRANSIT CONNECTOR

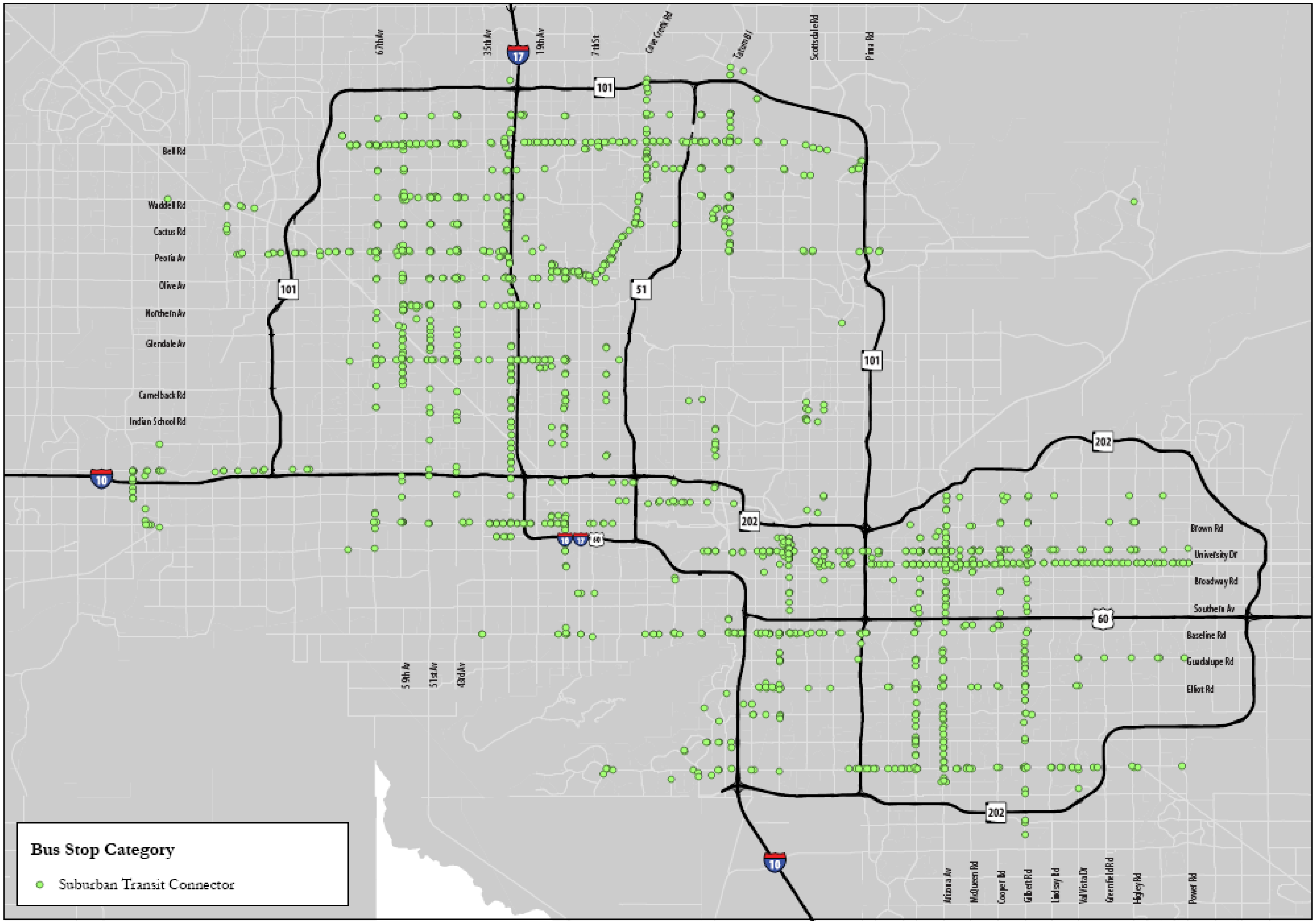


Figure 15
Bus Stop Categorization – Low Suburban Peak Hour Transit Connector

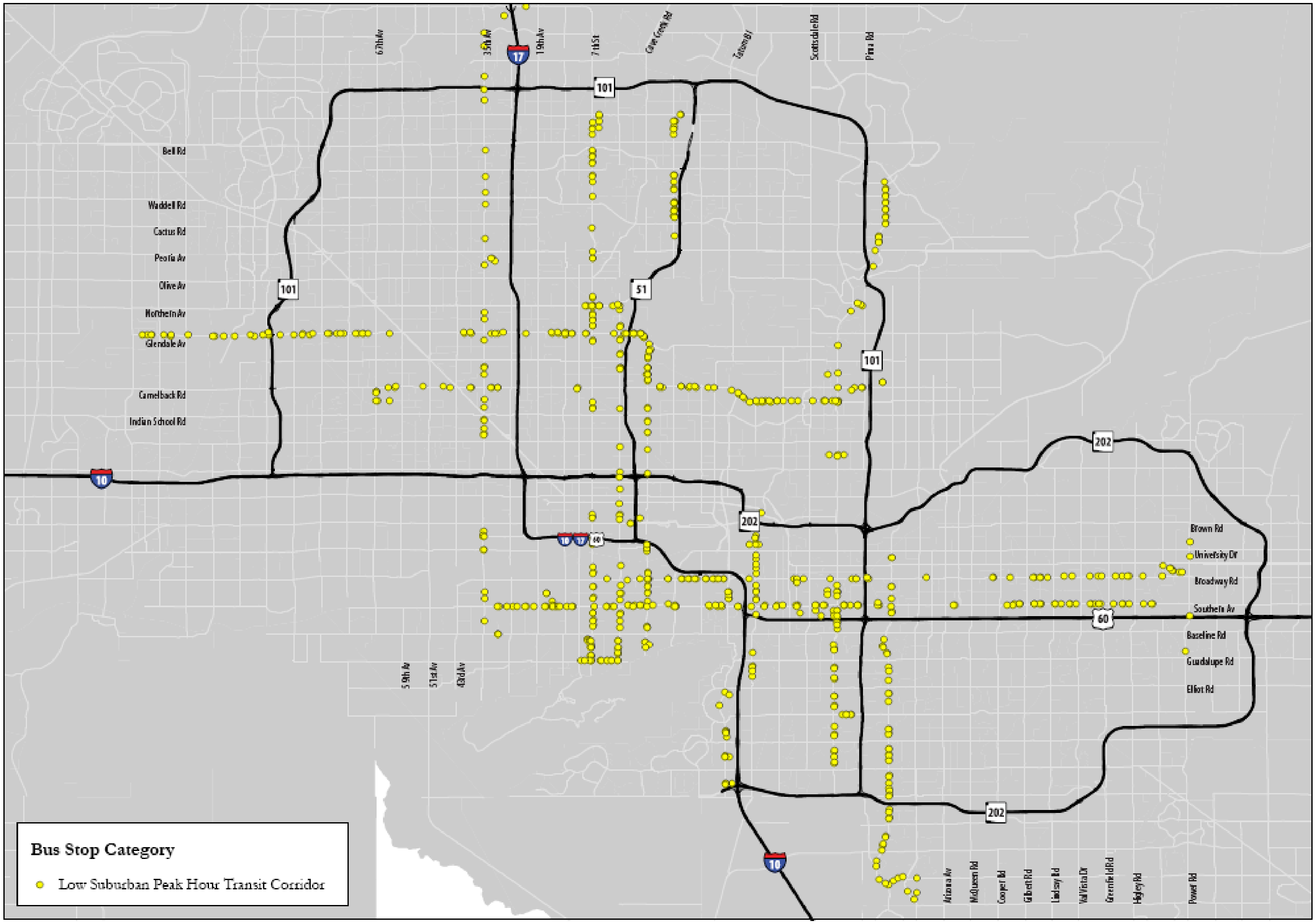
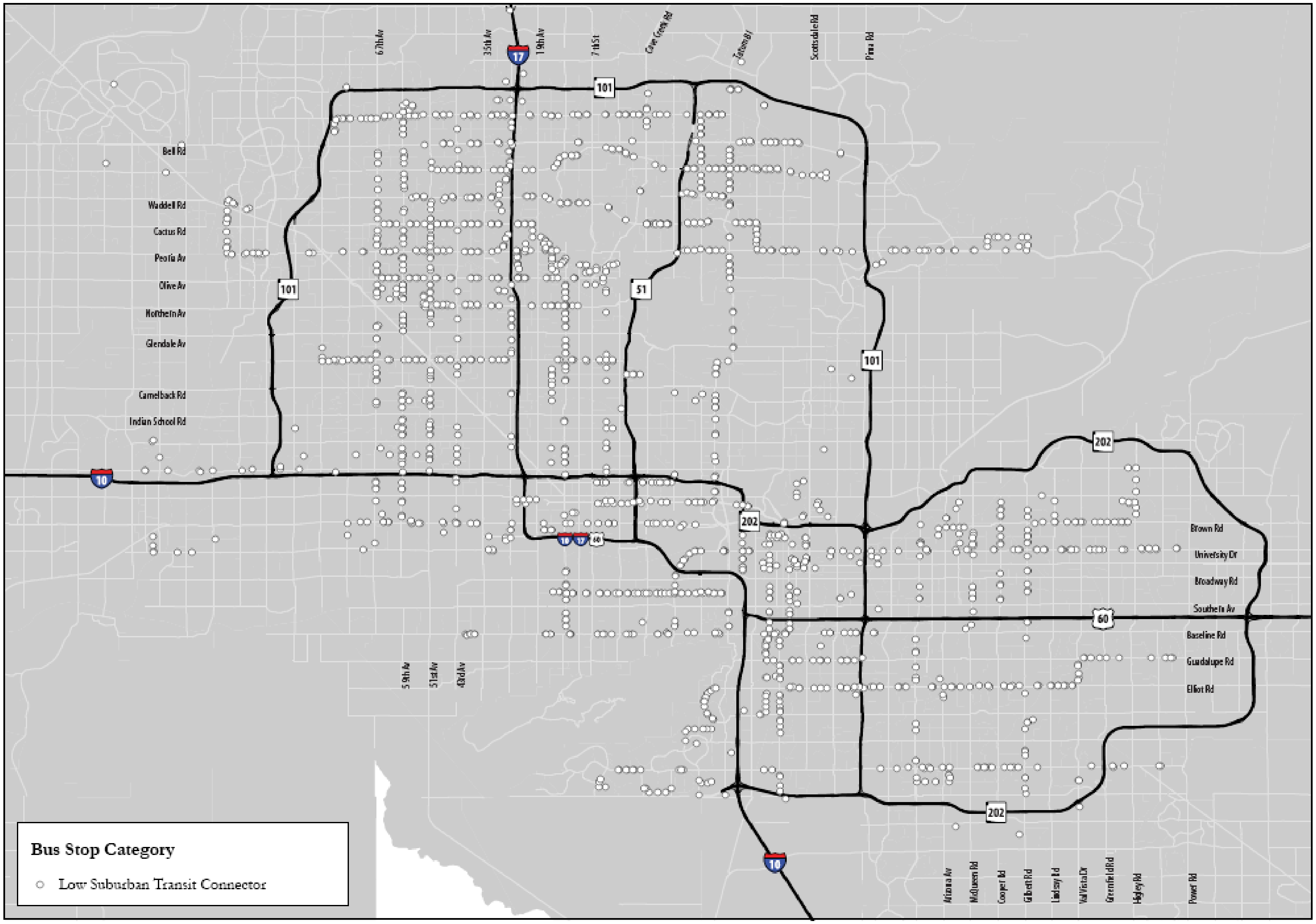


Figure 16
BUS STOP CATEGORIZATION – LOW SUBURBAN TRANSIT CORRIDOR



4.2 Ground-Truthing

The findings of the cluster analysis were validated and refined through several levels of "ground-truthing." The process of ground-truthing included the following types of reviews:

- Exploring the demographic and transit service characteristics of each category, as defined above in Table 7;
- Mapping each category individually and vetting the bus stop categorization with the Technical Working Group (TWG), as displayed above in Figures 9 – 16;
- Proposing preliminary case study areas and vetting them with the TWG;
- Examining the categories and preliminary case study locations through review of aerial imagery available through Google Earth; and
- Field-reconnaissance to review and verify selected cases from each category.

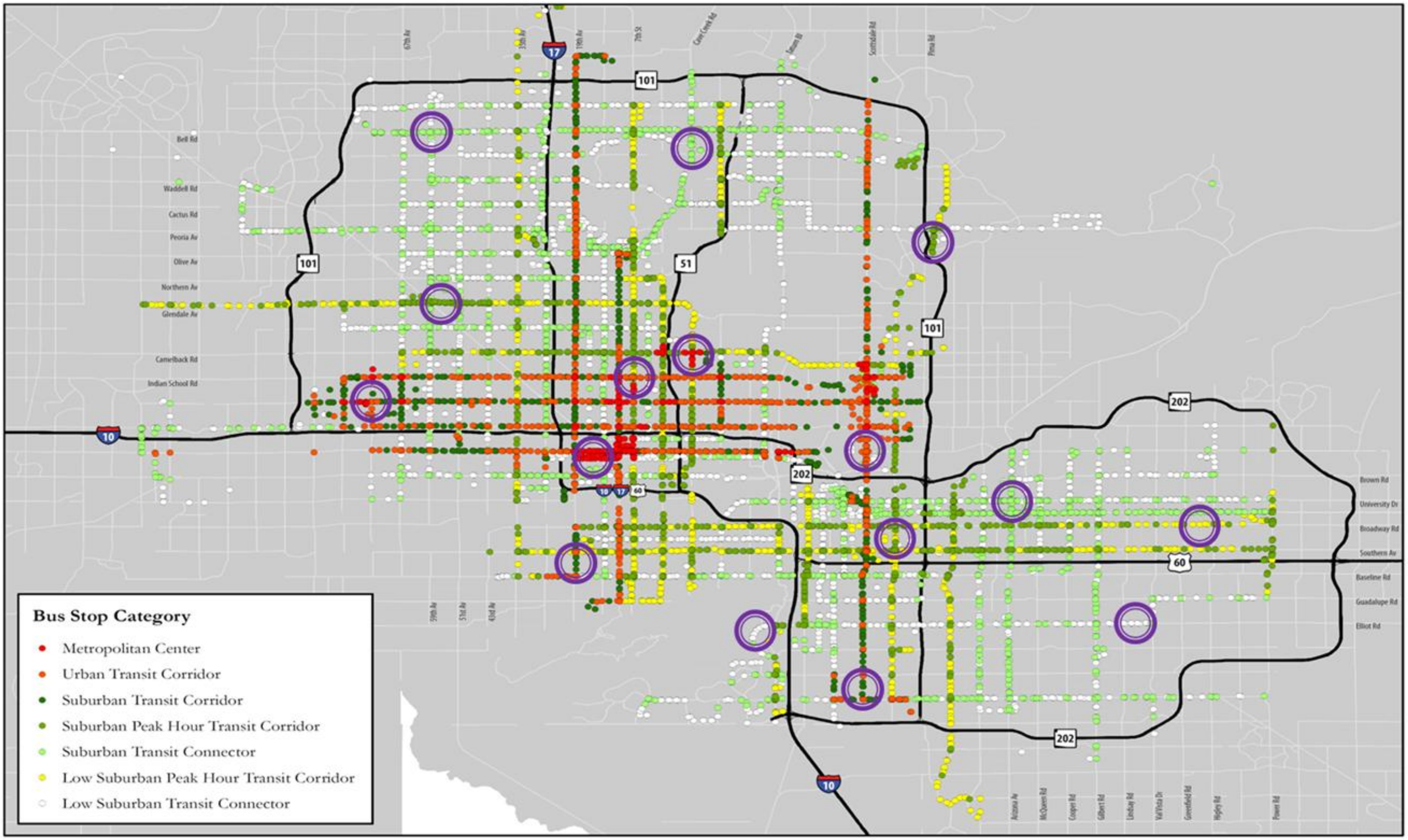
Table 8 and Figure 17 identify 16 potential locations selected for case study analysis and presented to the TWG for consideration. The Notes column in Table 8 provides information regarding the results of this initial evaluation of potential bus stop areas for case study purposes.

Table 8
PRELIMINARY CASE STUDY LOCATIONS

Category Ranking	Category Name	Location	Field Review	Notes
1	Metropolitan Core	24th Street & Camelback Road, Phoenix	No	16th Street & Thomas Road, Phoenix, was selected subsequent to TWG review
		10th Avenue & Washington, Phoenix	No	
2	Urban Transit Corridor	Indian School Road & 7th Street, Phoenix	No	--
		75th Avenue & Thomas Road, Phoenix	Yes	Preferred
		Scottsdale Road & Thomas Road, Scottsdale	Yes	--
3	Suburban Transit Corridor	Rural Road & Galveston Street, Chandler	No	19th Avenue & Southern Avenue, Phoenix, was selected subsequent to TWG review
		19th Avenue & Alta Vista Road, Phoenix	Yes	
4	Suburban Peak Hour Transit Corridor	90th Street & Mountain View Road, Scottsdale	Yes	90th Street, South of Shea Boulevard, Scottsdale, was selected subsequent to TWG review, as it offered greater opportunity for evaluating patron access relative to the Scottsdale Healthcare Shea Medical Center
		Glendale Road & 58th Avenue, Glendale	No	
5	Suburban Transit Connector	59th Avenue & Bell Road, Glendale	Yes	75th Avenue & Bell Road, Glendale, was selected subsequent to DTAC study team review, as it is closely associated with a major activity center, the Arrowhead Towne Center
		Cave Creek Road & Greenway Road, Phoenix	No	
		University Drive & Country Club Drive, Mesa	No	
6	Low Suburban Peak Hour Transit Corridor	McClintock Drive & Alameda Drive, Tempe	No	--
		48th Street & Broadway Road &, Mesa	Yes	Preferred, Very low ridership
7	Low Suburban Transit Connector	Elliot Road & Lakeview Drive, Gilbert	Yes	Preferred, Very low ridership
		Warner Elliot Loop & Equestrian Trail, Phoenix	No	--

Source: Chen Ryan Associates; May 2012.

Figure 17
POTENTIAL CASE STUDY LOCATIONS



After the categories and proposed case study locations were reviewed by the TWG and the DTAC study team, some of categories were collapsed. In particular, the Metropolitan Core and Urban Transit Corridor categories were collapsed into one category and renamed *Urban Transit Corridor*. Also, the Suburban Transit Connector and Low Suburban Transit Connector were collapsed and renamed *Low Suburban Transit Connector*. Subsequent to consolidation of bus stop area categories, five locations were selected as case study locations to be field-checked for reasonableness. Table 9 displays the final typology of bus stop area categories and locations selected for case study analysis. The Notes column in Table 9 provides information regarding the rationale for selecting these six locations. Figures 18 through 23 provide photographs of the final five locations determine to be viable candidates for case study.

Table 9
FINAL CASE STUDY LOCATIONS

Category Ranking	Category Name	Location	Notes
1	Urban Transit Corridor	16th Street & Thomas Road, Phoenix	The DTAC study time determined the Metropolitan Core and Urban Transit Corridor categories had similar characteristics. The 16th Street & Thomas Road location was selected over the 75th Avenue & Thomas Road location, because the stop has higher ridership, and there is greater opportunity for interaction with patrons to get feedback regarding route transfers and access to the bus stop.
2	Suburban Transit Corridor	19th Avenue & Southern Avenue, Phoenix	--
3	Suburban Peak Hour Transit Corridor	90th Street, South of Shea Boulevard, Scottsdale	--
4	Suburban Transit Connector	75th Avenue & Bell Road, Glendale	--
5	Low Suburban Transit Connector	Elliot Road & Lakeview Drive, Gilbert	Although this bus stop has very low ridership, the location was retained as a case study location, because the bus stop area offers numerous amenities and good access. As such, it represents a high quality suburban bus stop area, which differentiates it from the typical stop in this category.

Source: Chen Ryan Associates; May 2012.

Figure 18
URBAN TRANSIT CORRIDOR CASE STUDY LOCATION
16TH STREET & THOMAS ROAD, PHOENIX

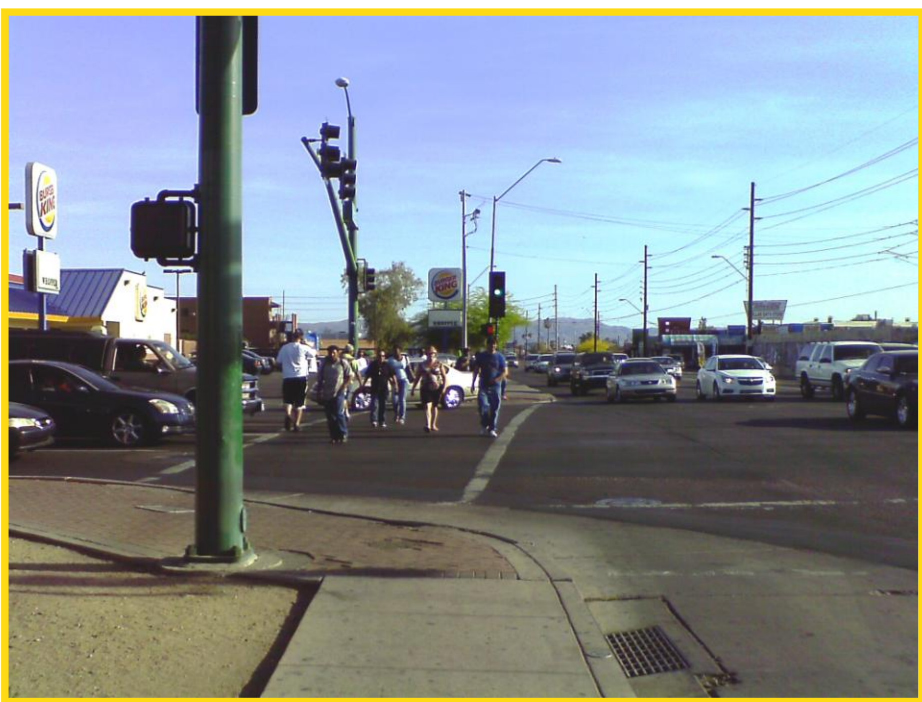


Figure 19
SUBURBAN TRANSIT CORRIDOR CASE STUDY LOCATION
19TH AVENUE & SOUTHERN AVENUE, PHOENIX

Figure 20
SUBURBAN PEAK HOUR TRANSIT CORRIDOR CASE STUDY LOCATION
90TH STREET, SOUTH OF SHEA BOULEVARD, SCOTTSDALE

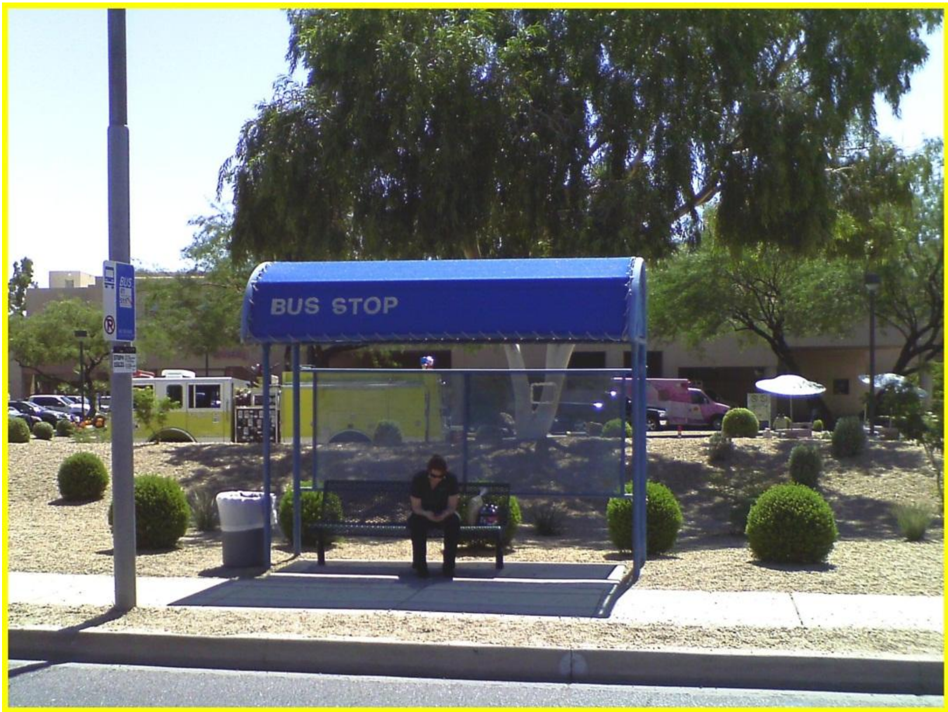


Figure 21
SUBURBAN TRANSIT CONNECTOR CASE STUDY LOCATION
75TH AVENUE & BELL ROAD, GLENDALE

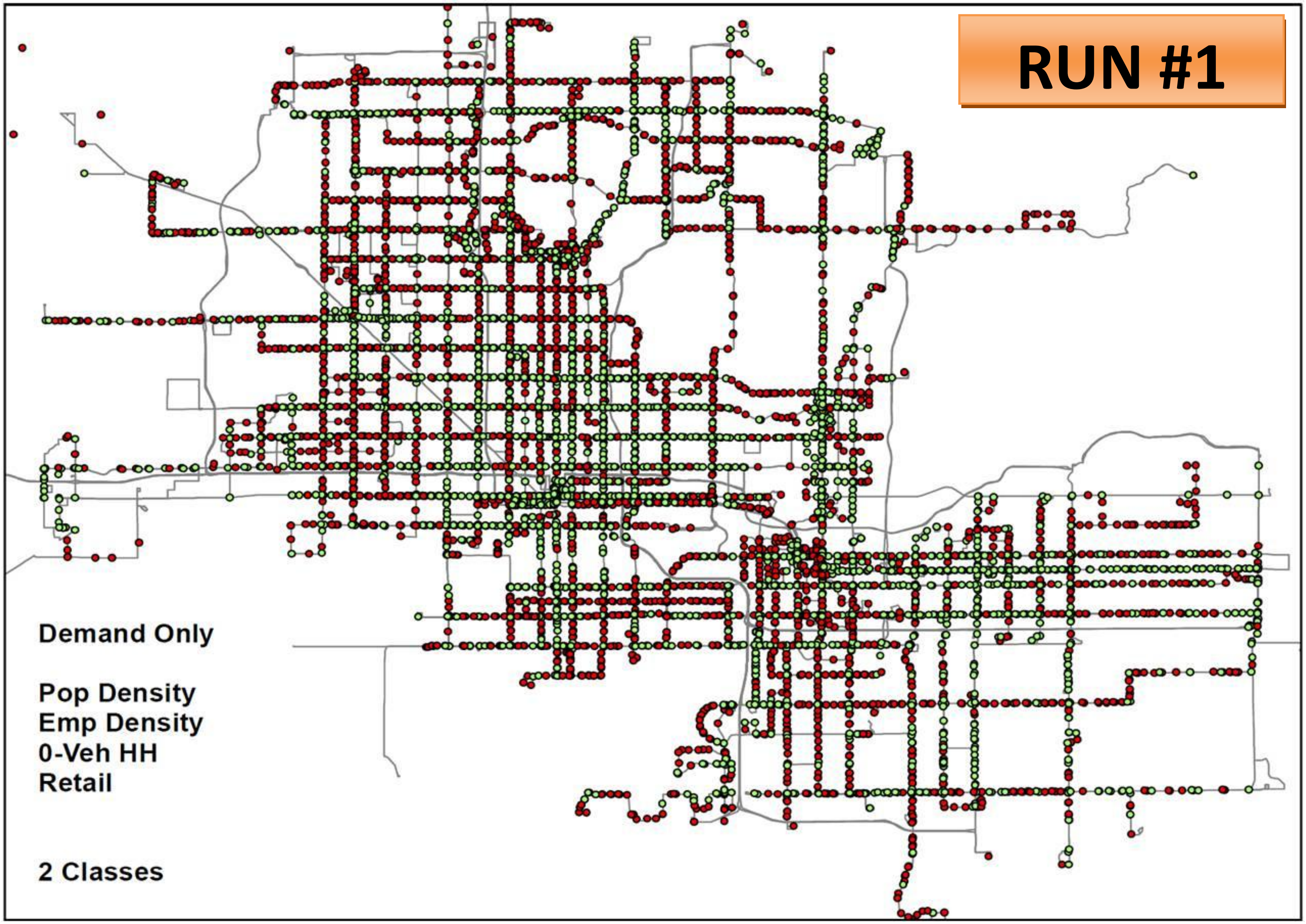
Figure 22
Low Suburban Transit Connector Case Study Location
Elliot Road & Lakeview Drive, Gilbert

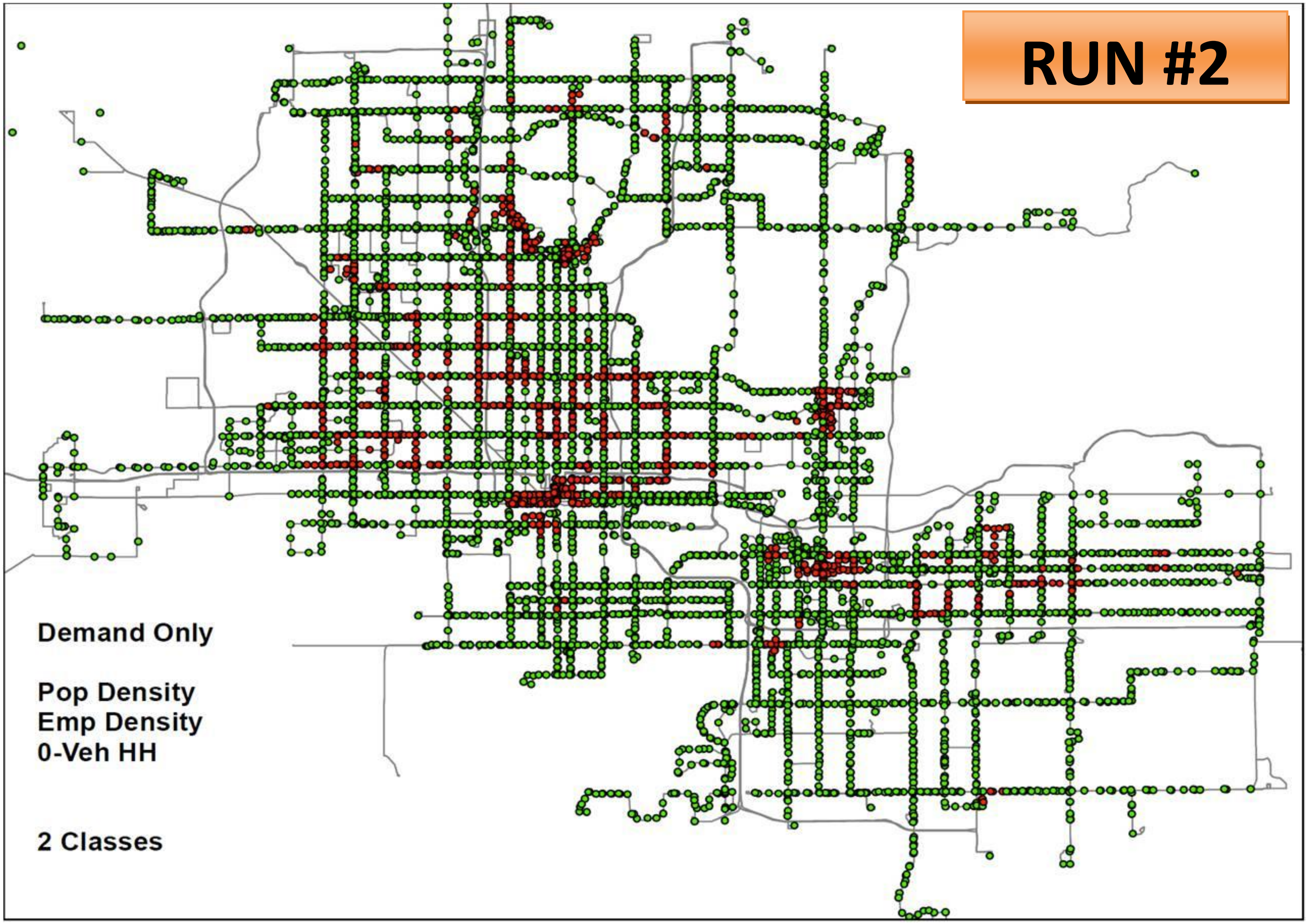
APPENDICES

APPENDICES – WORKING PAPER # 2, CATEGORIZATION OF BUS STOPS

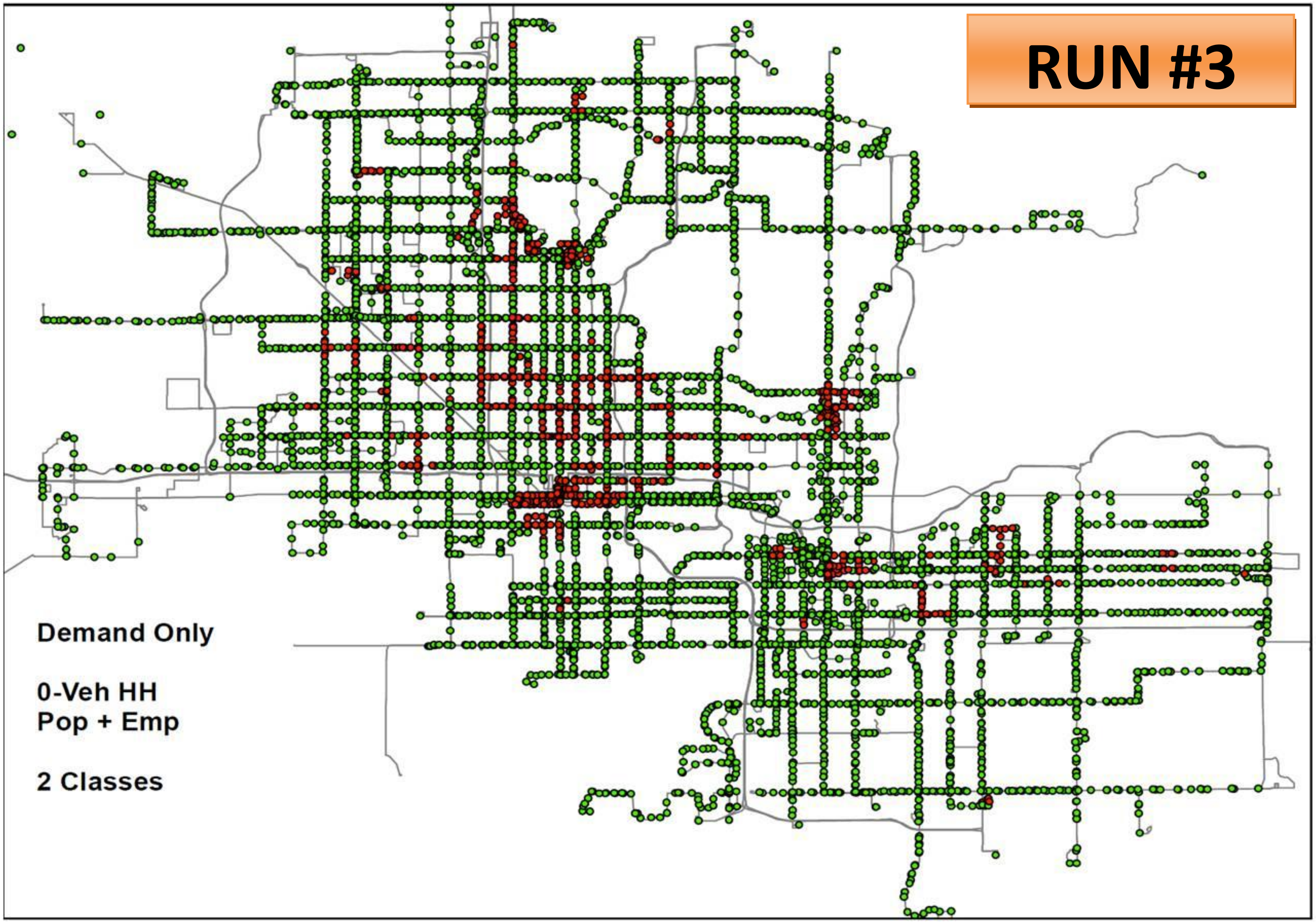
APPENDIX A

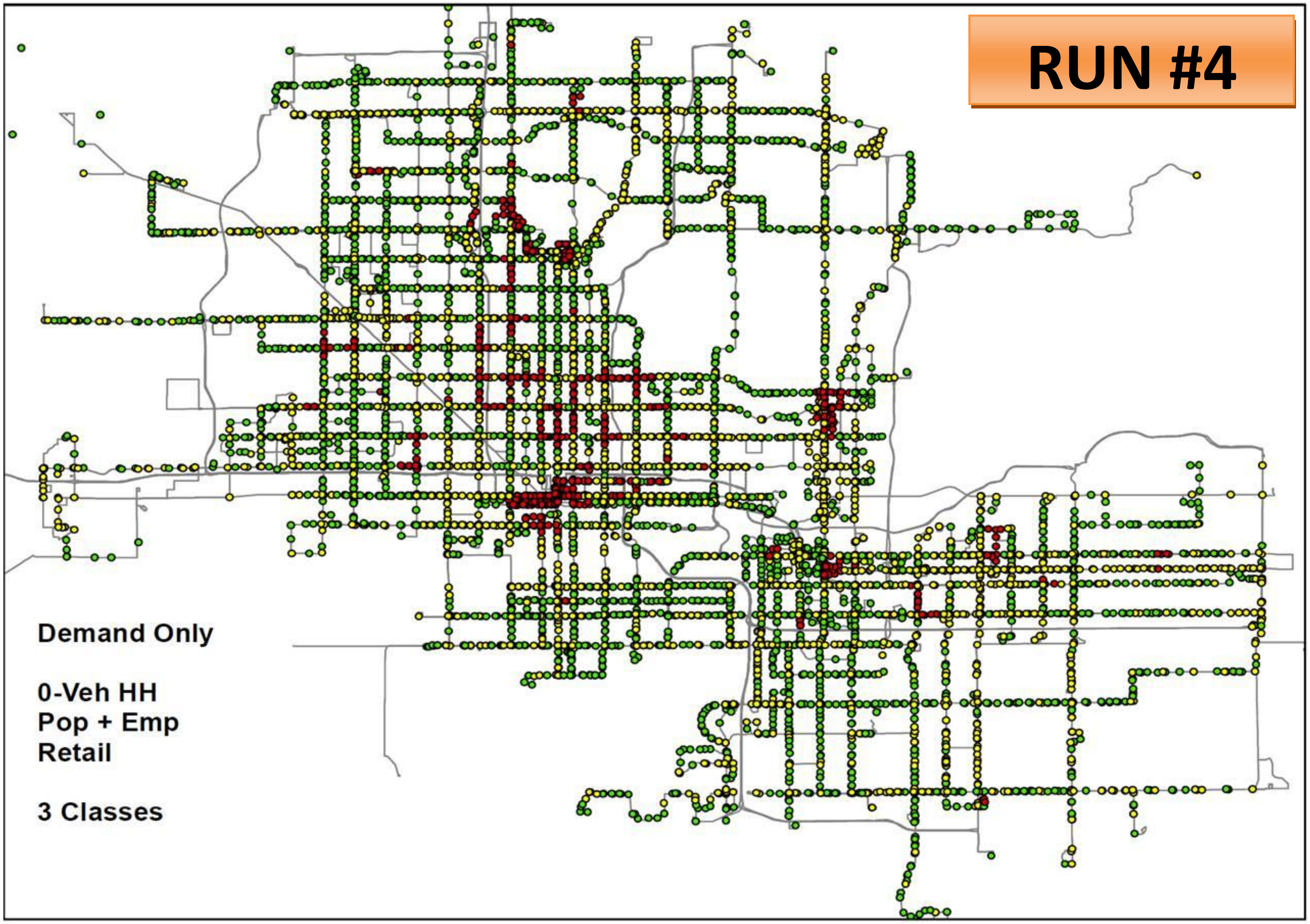
CLUSTER MODEL RUNS #1 – # 4


RUN #1
Demand Only
Pop Density
Emp Density
0-Veh HH
Retail
2 Classes


RUN #2
Demand Only
Pop Density
Emp Density
0-Veh HH
2 Classes

July, 2012

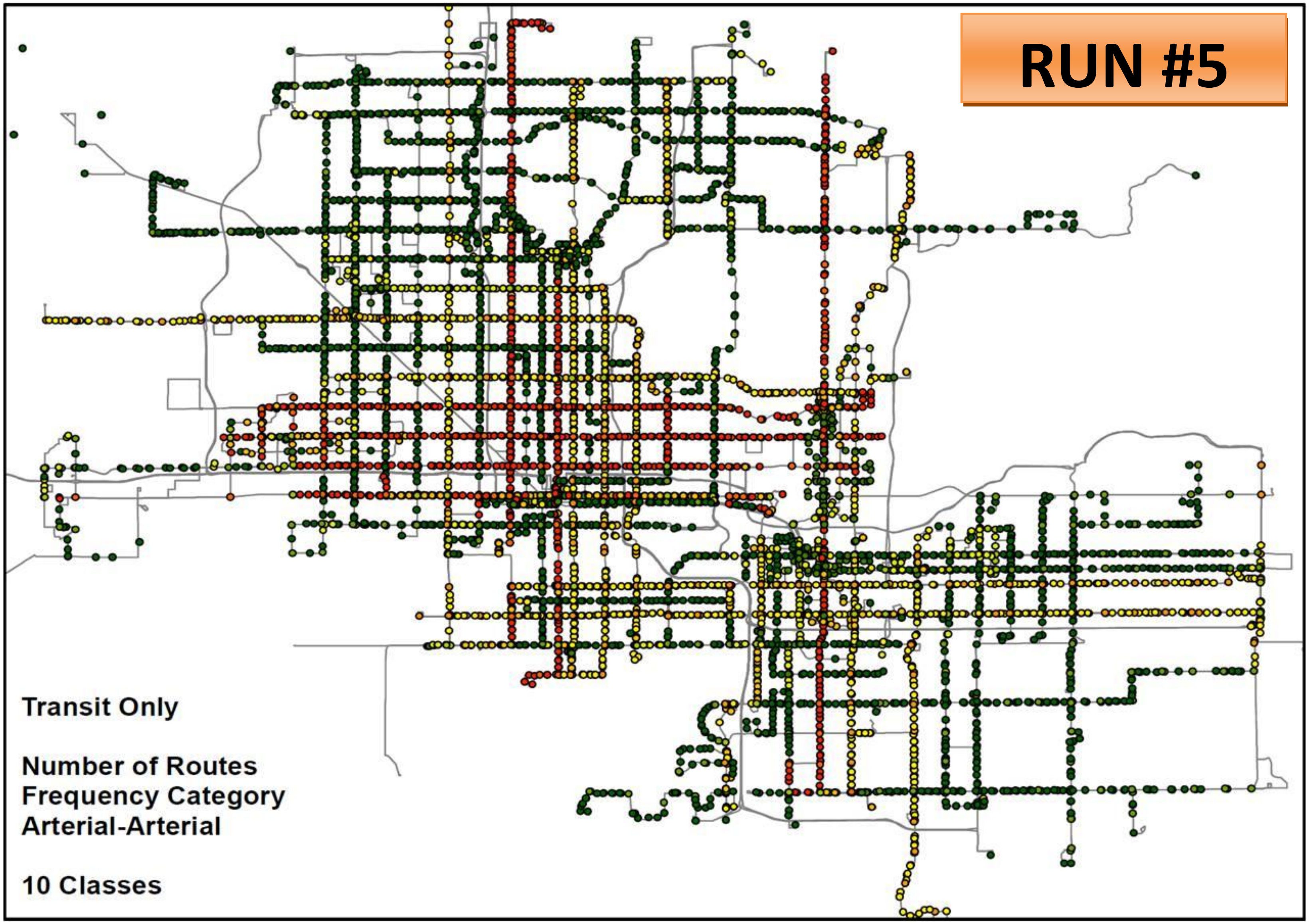



RUN #4
Demand Only
0-Veh HH
Pop + Emp
Retail
3 Classes

APPENDIX B

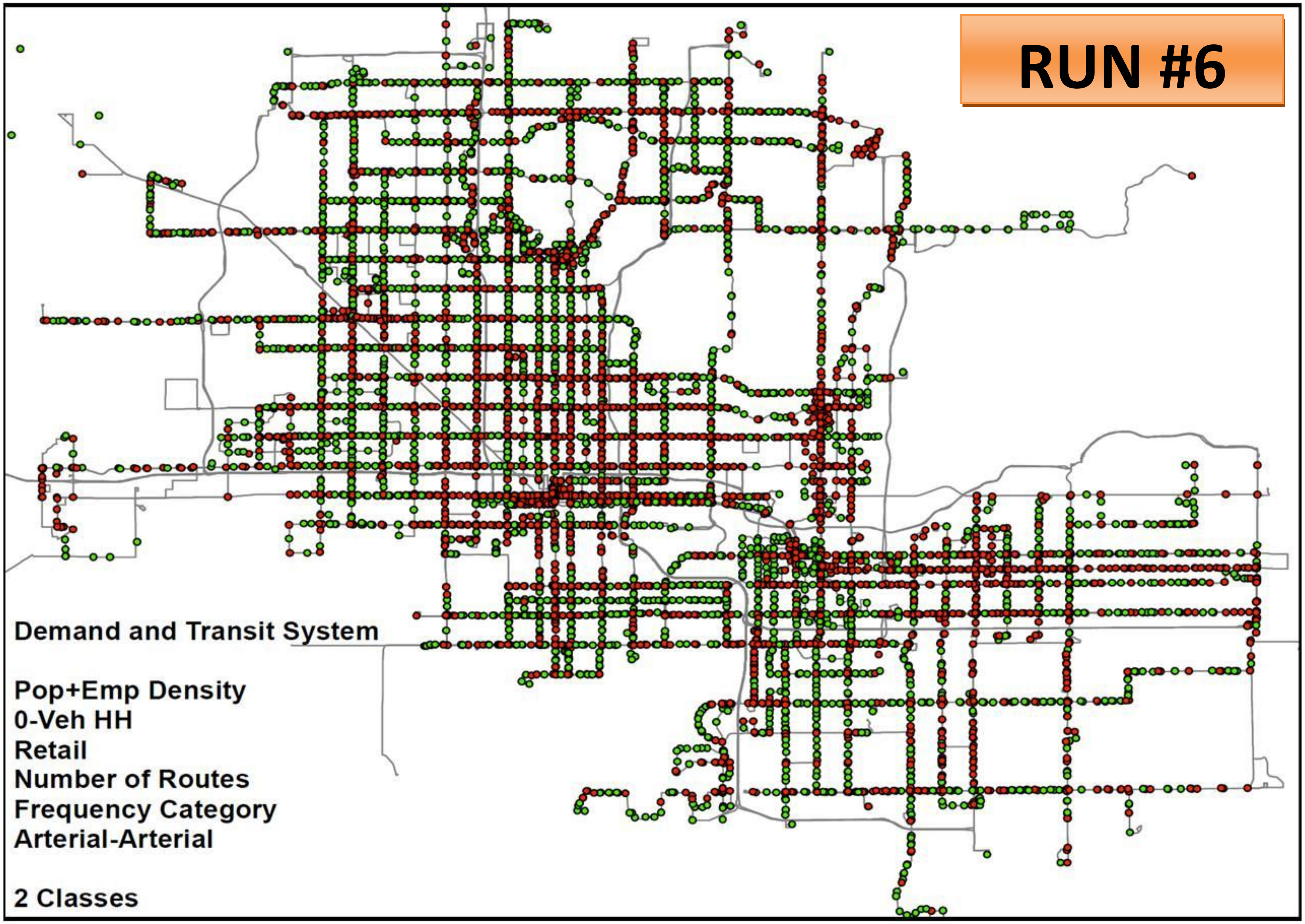
CLUSTER MODEL RUN #5

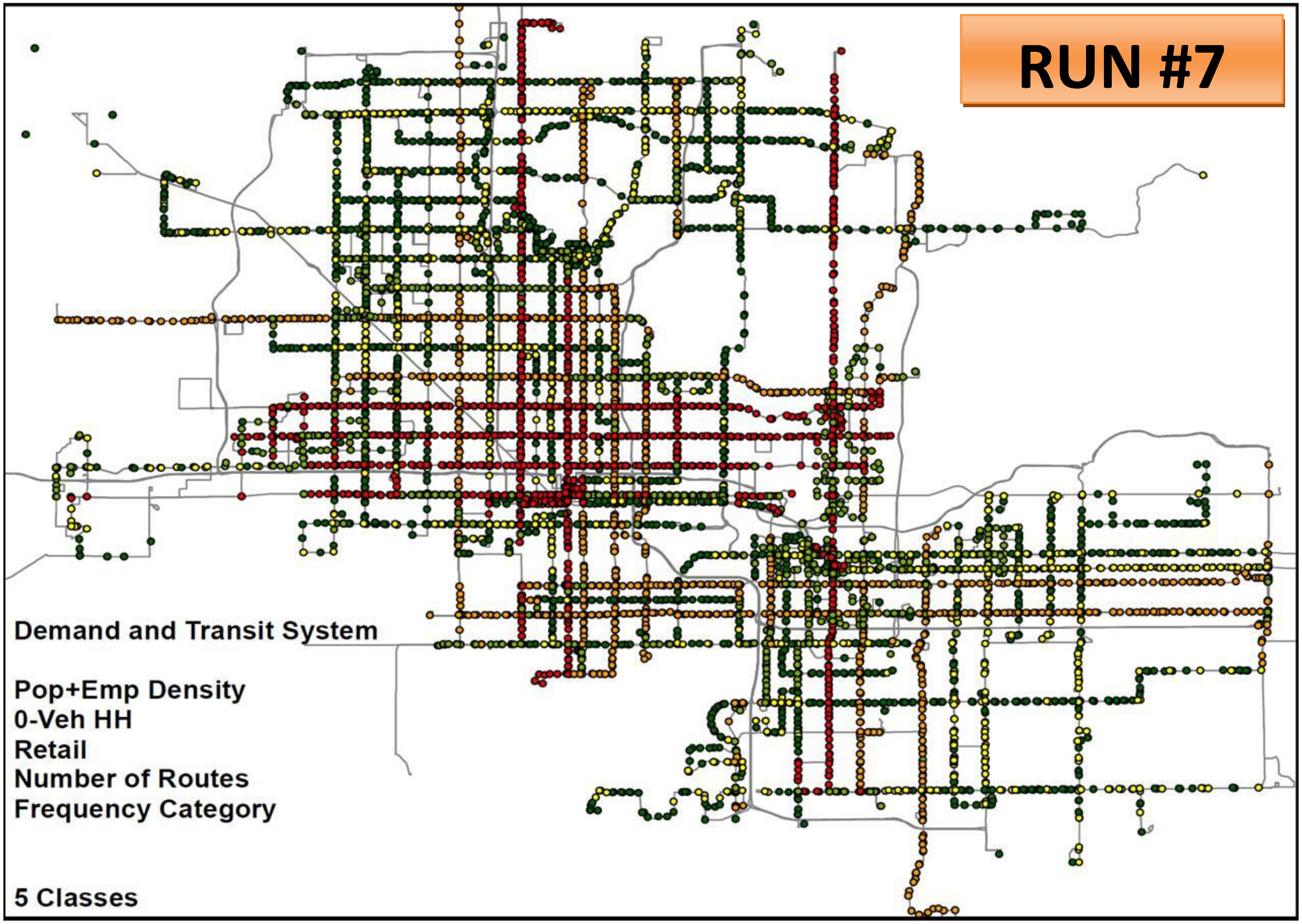
July, 2012

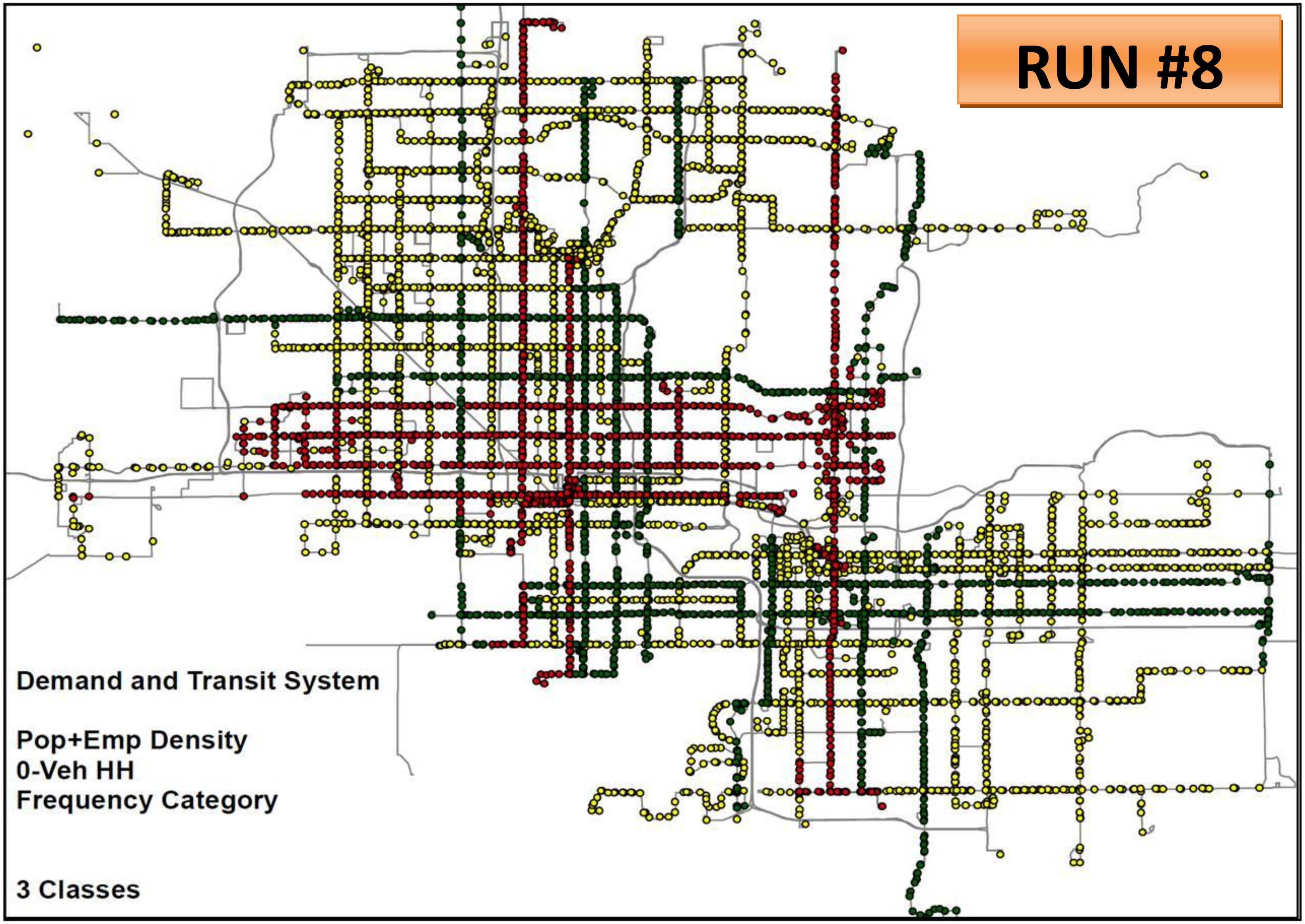

RUN #5
Transit Only
Number of Routes
Frequency Category
Arterial-Arterial
10 Classes

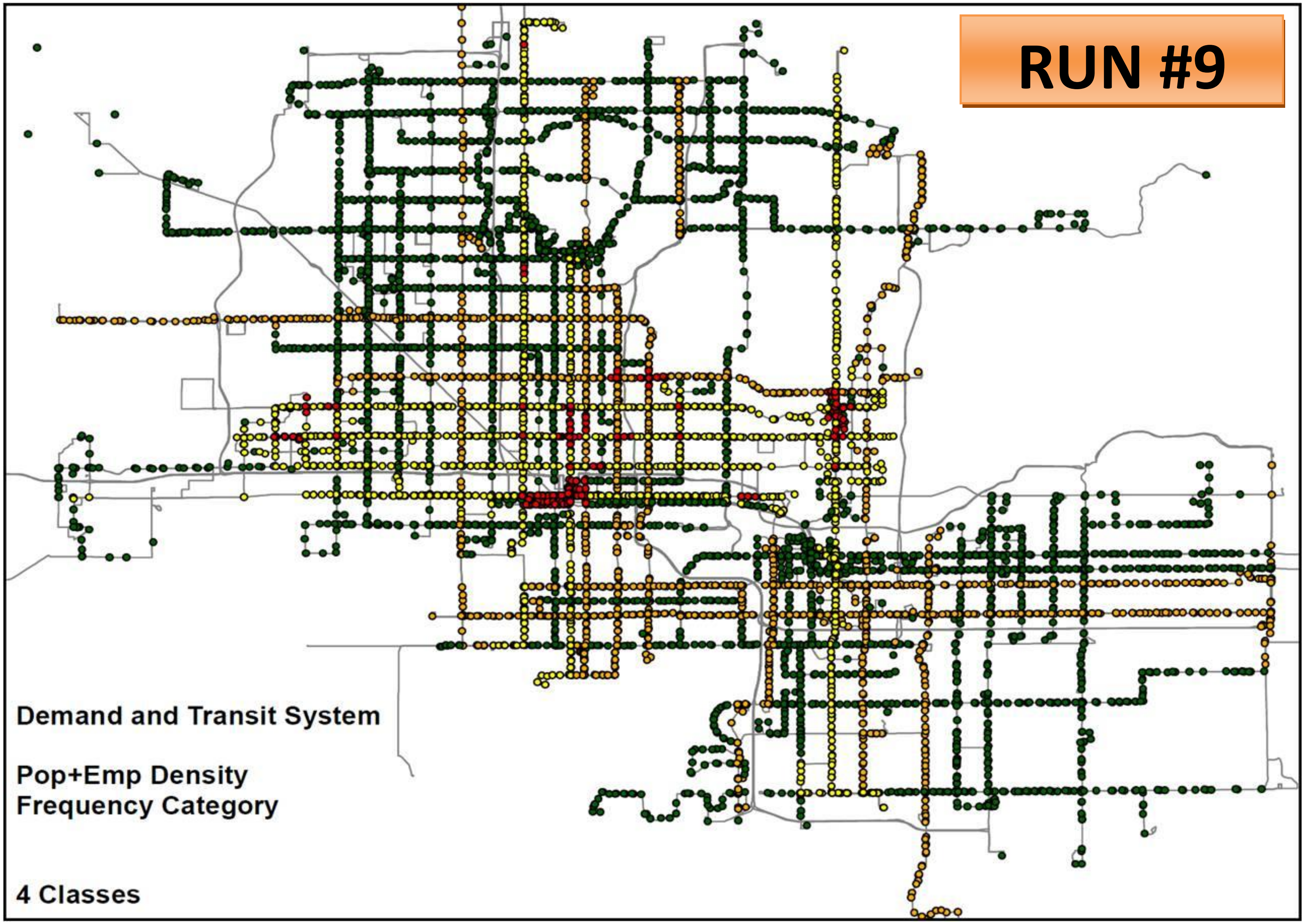
APPENDIX C

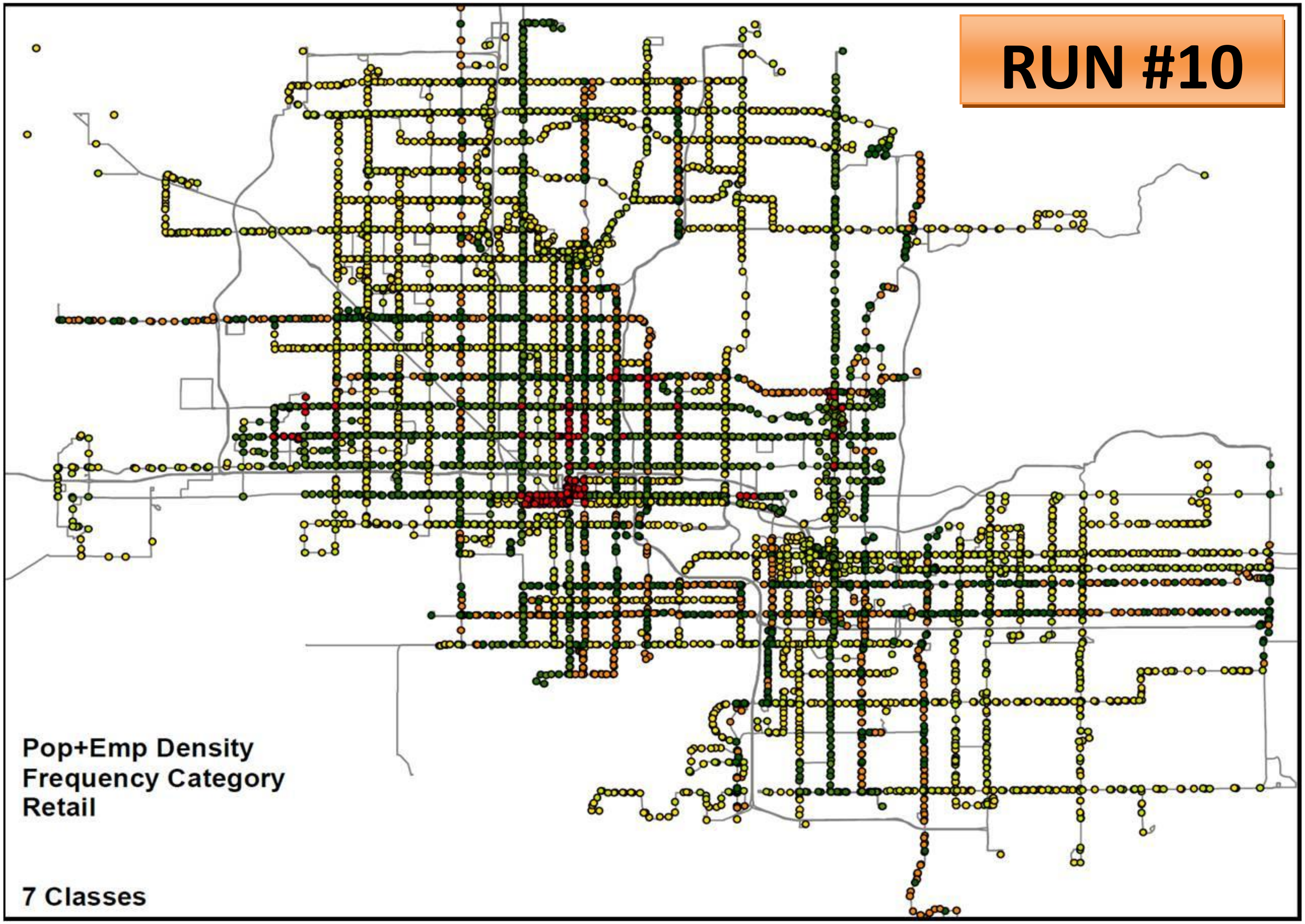
CLUSTER MODEL RUNS #6 – #10


RUN #6
Demand and Transit System
Pop+Emp Density
0-Veh HH
Retail
Number of Routes
Frequency Category
Arterial-Arterial
2 Classes


RUN #7
Demand and Transit System
Pop+Emp Density
0-Veh HH
Retail
Number of Routes
Frequency Category
5 Classes


RUN #8
Demand and Transit System
Pop+Emp Density
0-Veh HH
Frequency Category
3 Classes


RUN #9
Demand and Transit System
Pop+Emp Density
Frequency Category
4 Classes


RUN #10
Pop+Emp Density
Frequency Category
Retail
7 Classes