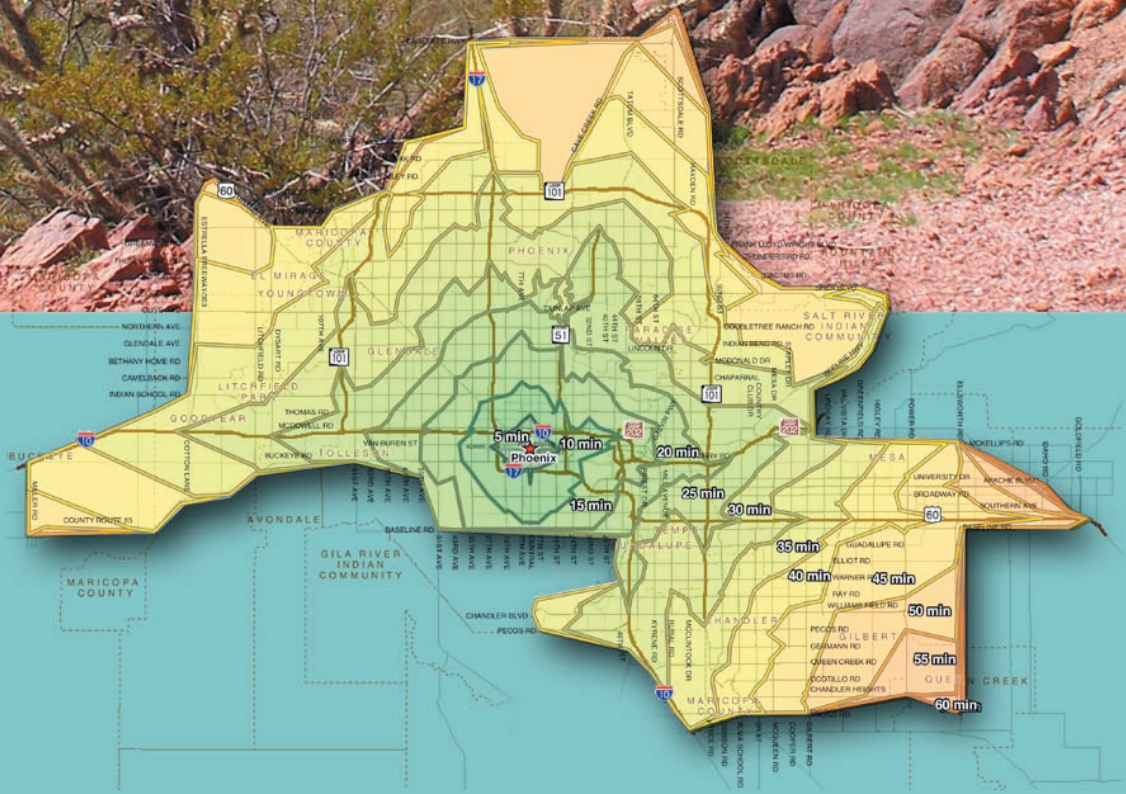
MARICOPA ASSOCIATION of GOVERNMENTS

2002-2003 MAG Regional Travel Time & Travel Speed Study

Prepared for:
Maricopa Association of Governments
302 N. 1st Avenue
Phoenix, AZ 85003

April 26, 2004



Carter Burgess

7950 Elmbrook Drive, Dallas, Texas 75247 Phone: 214-638-0145 Fax: 214-638-0447

April 27, 2004

Ms. Ratna Korepella
Project Manager
Maricopa Association of Governments
302 North 1st Avenue
Phoenix, Arizona 85003

RE: 2002-2003 Regional Travel Speed Study

Dear Ms. Korepella:

Carter & Burgess, Inc. is pleased to submit this report summarizing the results of the 2002-2003 Regional Travel Speed Study performed for the Maricopa Association of Governments (MAG). This report is the culmination of almost 2 years of teamwork between Carter & Burgess, Traffic Research and Analysis (TRA), Dr. Darcy Bullock, and MAG staff. As you know, this project was groundbreaking in many ways including the scale, technology, data management, and its comprehensive nature.

The scale of the project encompassed the MAG region for all primary arterials, freeways, and HOV lanes including over 1,800 centerline miles of roadway. Following the travel time runs that began in August 2002 and were completed in July 2003, the total number miles driven exceeded 70,000. The technology developed and applied to this project, including differentially corrected 1-second GPS points and geo-referenced digital video, produced a large amount of data that will be used for years to come by MAG and its members. The data management was critical to the success of the project given the amount of data that was generated on a weekly basis. In a typical week, almost 3,000 miles and 350,000 1-second points were collected for analysis. Without a robust system in place to collect, process, provide quality control, and evaluate efficiently, the amount of data would have quickly become overwhelming. The primary goal of the project was to determine the average speeds on the study roadways, but through the system developed, the detail included in the database and accompanying geographic information system (GIS), MAG will benefit with details not previously known about the region's network.

The Carter & Burgess team wants to compliment MAG and its staff for its support throughout the project. We received valuable insight in designing a project approach that collected a wealth of data for use in calibrating the travel demand model and various other platforms. This project has truly been a rewarding effort, and we look forward to continued involvement with MAG in the future.

Sincerely,
Carter & Burgess, Inc.

Steve T. Taylor, P.E., PTOE
Carter & Burgess, Inc. - Project Manager

Robert Medland
Traffic Research and Analysis, Inc.

Carter Burgess

TRA TRAFFIC RESEARCH & ANALYSIS, INC.
Specializing in Traffic Data Collection

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1.0 Executive Summary

1.1 Study Purpose

It is necessary for municipal planning organizations (MPO) to maintain an accurate, up to date regional transportation model in order to conform with State and Federal regulations for air quality and transportation projects. MPO's update and calibrate their models using current information on the roadway network, area development, and other relevant characteristics such as travel time and speed data. The Maricopa Association of Governments updates their travel time and speed data periodically. Updates historically have been completed since the 1950's including the most recent one in 1993.

The primary purpose of this year's 2002-2003 Travel Speed Study was to calibrate and validate the regional planning model. A secondary purpose was to compare this year's data with data from previous years to identify trends in congestion and travel time in order to identify problem locations for possible improvements. The project specifications developed by MAG produced the largest travel study in the country by covering almost 70,000 miles of runs over the 1,800 centerline miles in the region.

1.2 Study Method

The 2002-2003 Travel Speed Study was conducted using the floating car method as in previous studies, but with enhancements to the data collection, data management, and analytical methods. The study was conducted so that results could be compared with the results of the 1979, 1986, and 1993 Travel Time Studies in order to identify trends and changes in the roadway network and characteristics.

The roadways were mapped to establish centerlines and record relevant roadway features. Features located in the mapping process included: speed limits, school zones limits, and intersection control. Other elements were added using reference materials provided by MAG. Those include: area type, facility type, intersection geometry (historic and aerial), and city limits (MPA boundary).

Table 1 summarizes the number of miles driven in each jurisdiction during each period.

Table 1 – Miles by Jurisdiction

City	Directional Miles	AM Travel Miles	MD Travel Miles	PM Travel Miles	Total Travel Miles
Apache Junction	24.4	199.3	77.3	196.4	472.9
Avondale	31.9	288.6	103.8	313.1	705.5
Buckeye	40.0	337.9	144.3	355.3	837.6
Carefree	3.0	25.2	8.9	26.6	60.7
Cave Creek	2.4	20.8	8.5	22.2	51.5
Chandler	238.0	2051.0	740.2	2071.0	4862.1
El Mirage	17.2	155.9	51.5	149.7	357.0
Fountain Hills	8.0	66.0	30.3	78.5	174.7
Gila River	23.8	202.2	78.5	204.8	485.5
Gilbert	82.5	716.0	245.3	698.4	1659.7
Glendale	223.6	2063.0	712.1	2046.5	4821.7
Goodyear	52.1	443.9	183.1	472.5	1099.5
Guadalupe	8.6	126.5	52.9	125.5	304.9
Litchfield Park	5.2	48.7	15.7	48.7	113.1
Maricopa County	39.3	318.4	123.3	346.1	787.7
Mesa	379.8	3464.1	1272.0	3540.3	8276.4
Paradise Valley	22.1	226.5	66.7	203.5	496.8
Peoria	93.1	859.5	293.4	873.5	2026.4
Phoenix	1304.1	13113.1	4765.5	13438.6	31317.2
Queen Creek	21.4	179.3	72.5	183.2	435.0
Salt River	60.3	505.7	237.3	546.0	1289.1
Scottsdale	202.2	1866.2	662.5	1879.9	4408.6
Surprise	43.0	408.3	140.1	381.8	930.3
Tempe	205.7	2243.5	830.5	2326.0	5400.0
Tolleson	8.0	82.7	28.1	83.1	193.9
Total	3139.7	30012.4	10944.1	30611.3	71567.8

Travel speed data was collected from September 2002 through June 2003 on Tuesdays, Wednesdays, and Thursdays, during the morning and afternoon peak, and during the midday off-peak period as follows:

- Morning Peak Period: 6:30 to 8:30 AM
- Midday Off-Peak Period: 9:00 to 11:00 AM
- Afternoon Peak Period: 4:00 to 6:00 PM

Roadways included arterials, freeways, and HOV lanes. There were a total of 19 runs in each direction (8 in each direction in the AM/PM peak and 3 in the midday) on each

roadway included in the study with 15-minute headways to show variation during the peak periods. The number of runs was assigned by MAG.

The power of the data collected is that is can for detailed in a variety of forms in both figures and tables. It can be shown in it raw form as in **Figure 1** that includes the 1-second points from the travel time runs. Summarizing the data between each intersection for each run produces values for speed as shown in **Figure 2**. This figure demonstrates the variability of the speed over the 2-hour time period. By averaging all runs together within each segment for each of the time periods (AM, midday, and PM), a summary of the data is produced as shown in **Figure 3**. At times, it is desired to determine how much below the posted speed is the resulting average segment speed. By comparing the resulting average speed to the coded speed limits, the % of posted speed is displayed as shown in **Figure 4**. This is an interesting measure of effectiveness (MOE), but since the length of each segment varies, it sometimes indicates longer delays on the shorter segments. This is due to the longer segments having more time to wash out delays that may have occurred. To address this element, an additional MOE was implemented that utilized a common unit of length so that all segments were compared on an even plane. **Figure 5** illustrates this MOE and uses a segment length of 0.1 mile or a little over 500 feet.

Figure 1 – 1-Second GPS Points Detail

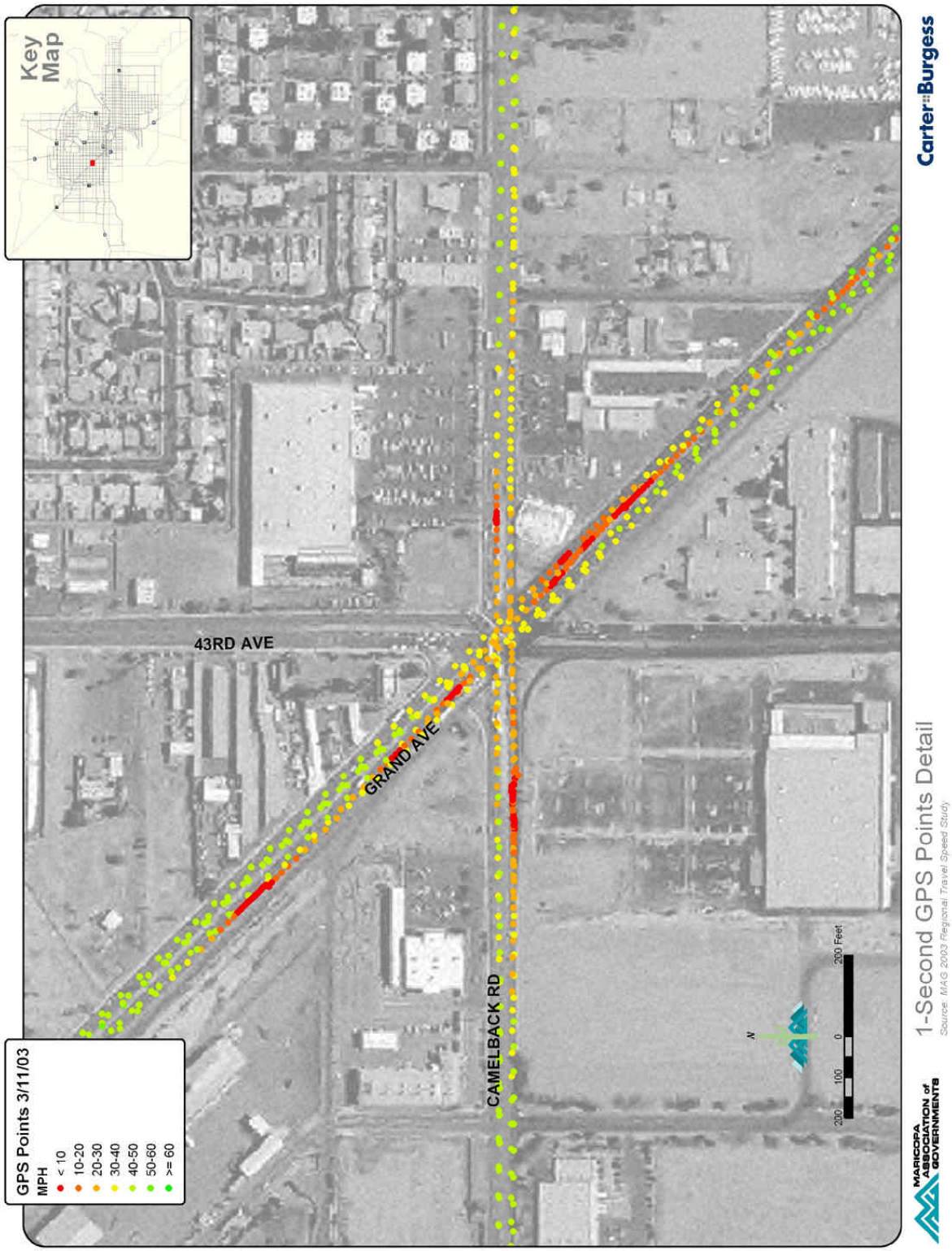


Figure 2 – Average Arterial Speed by 15-Minute Time Period - PM

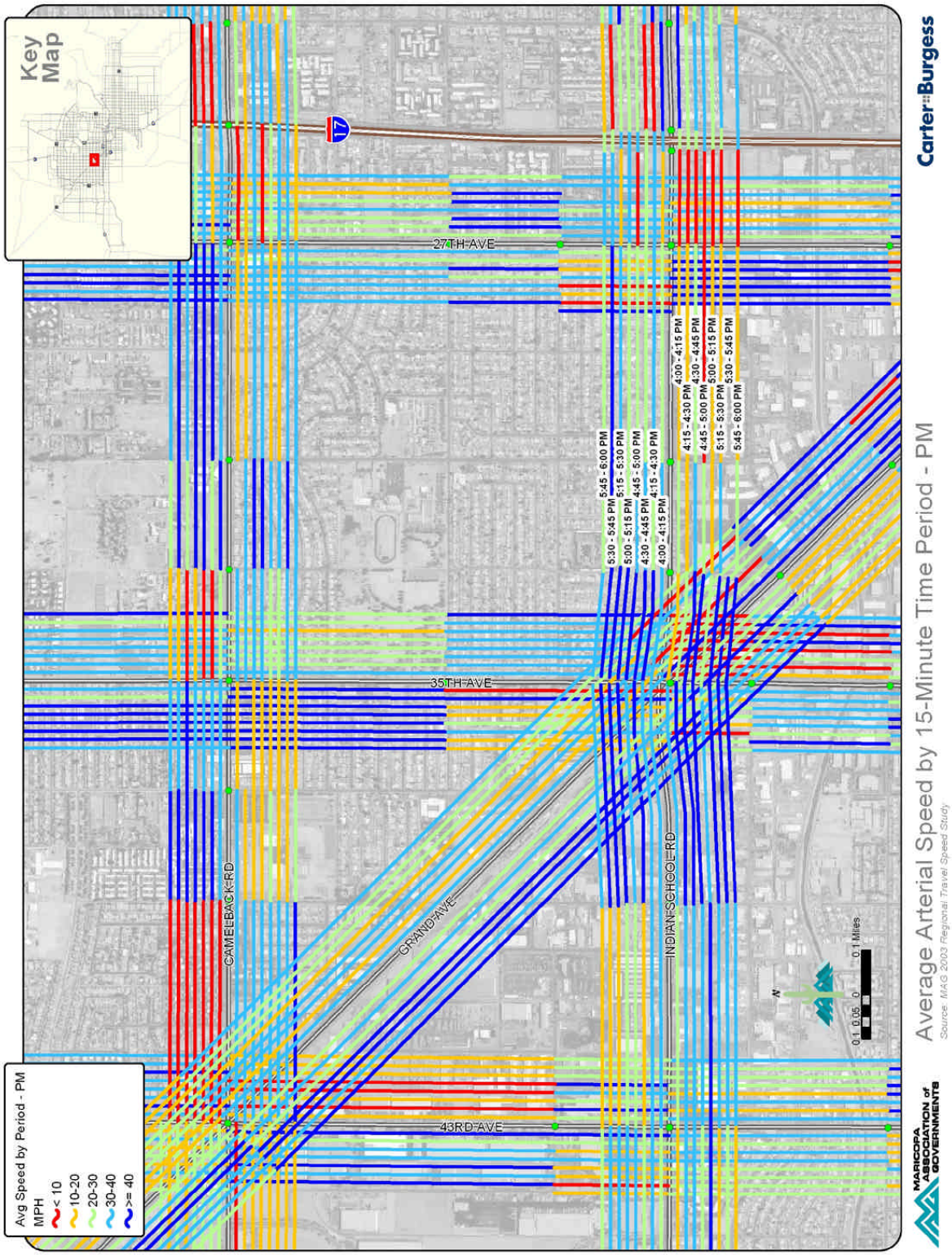


Figure 3 – Average Arterial Speed – PM (Detail)

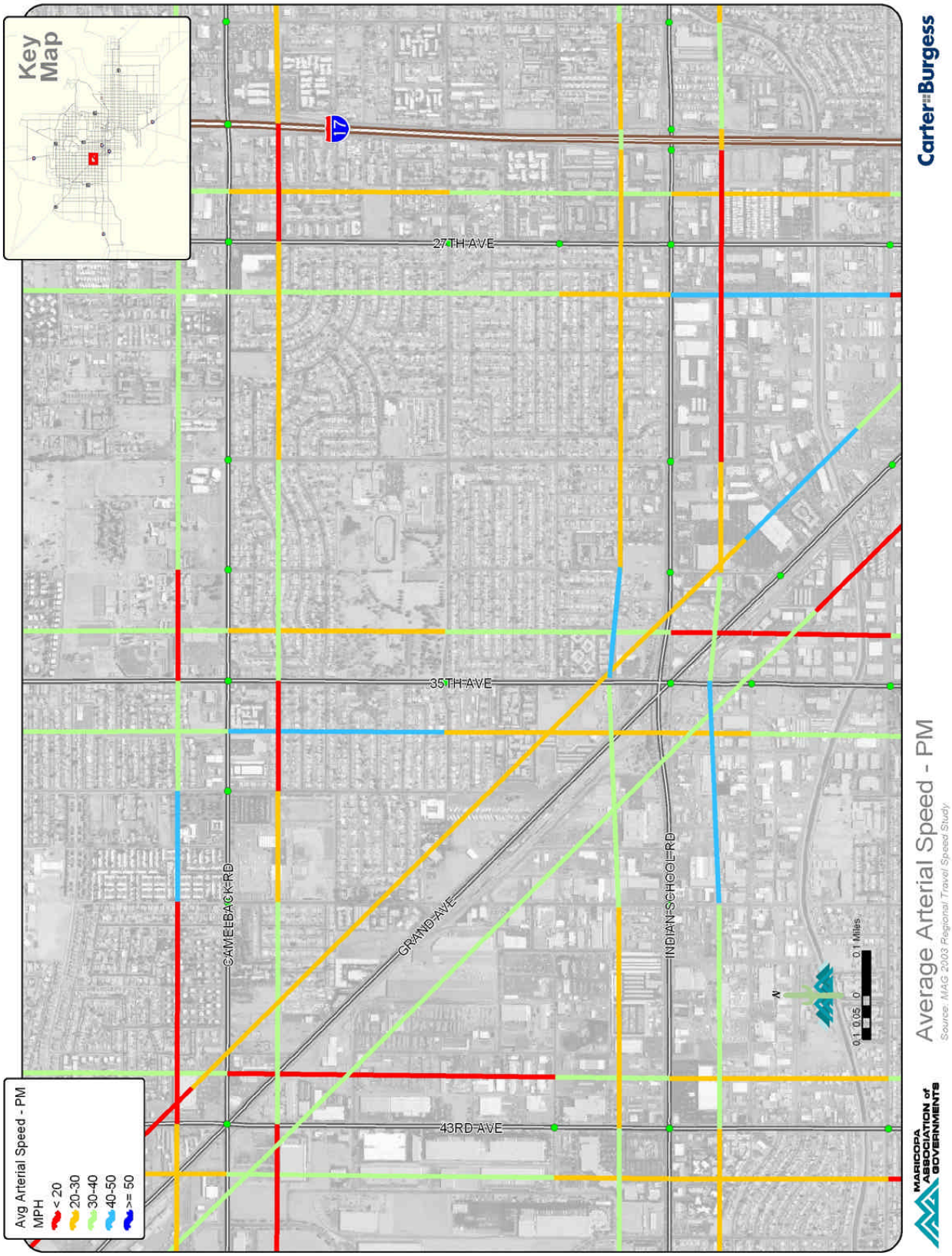


Figure 4 – Average Percent Posted Speed – PM (Detail)

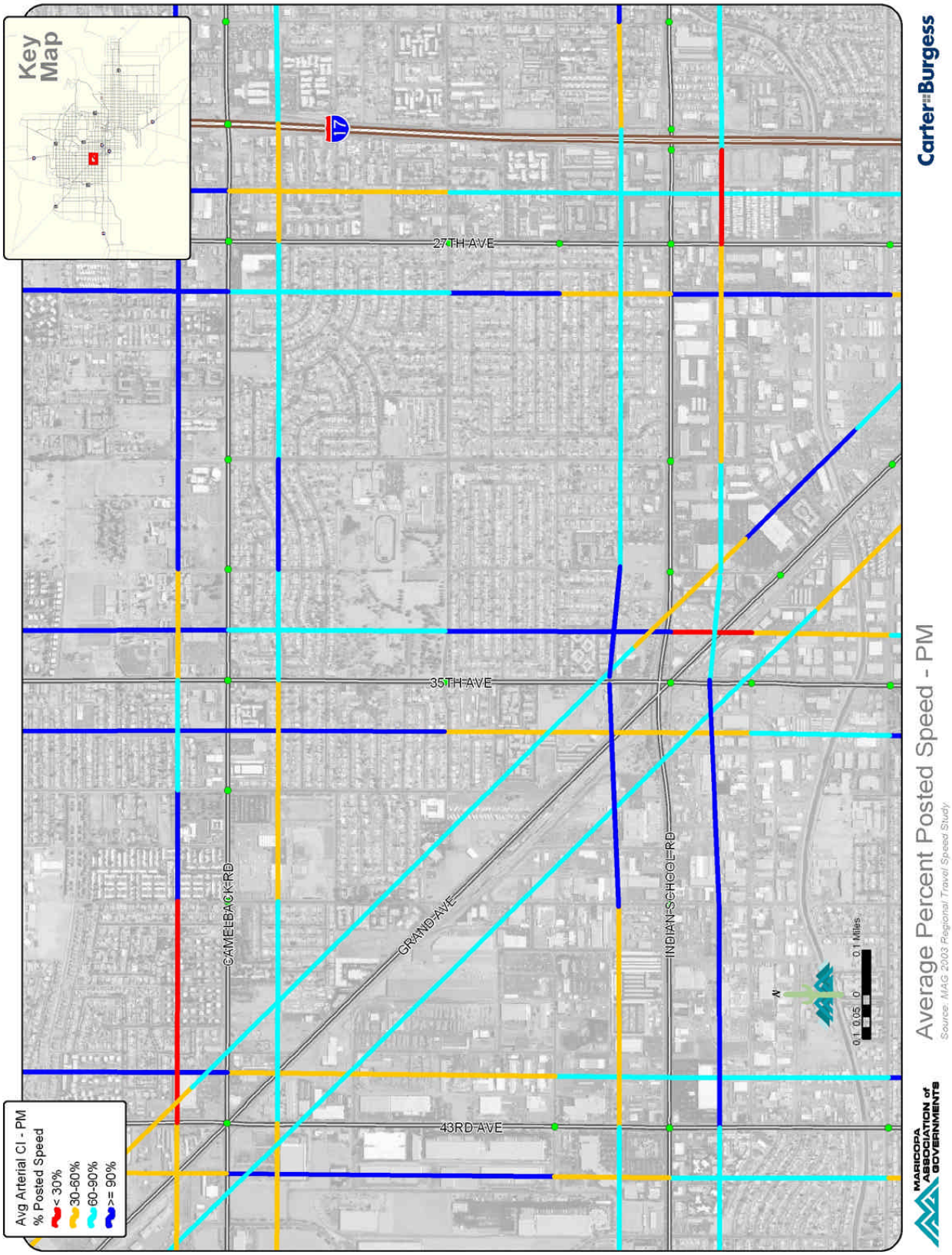
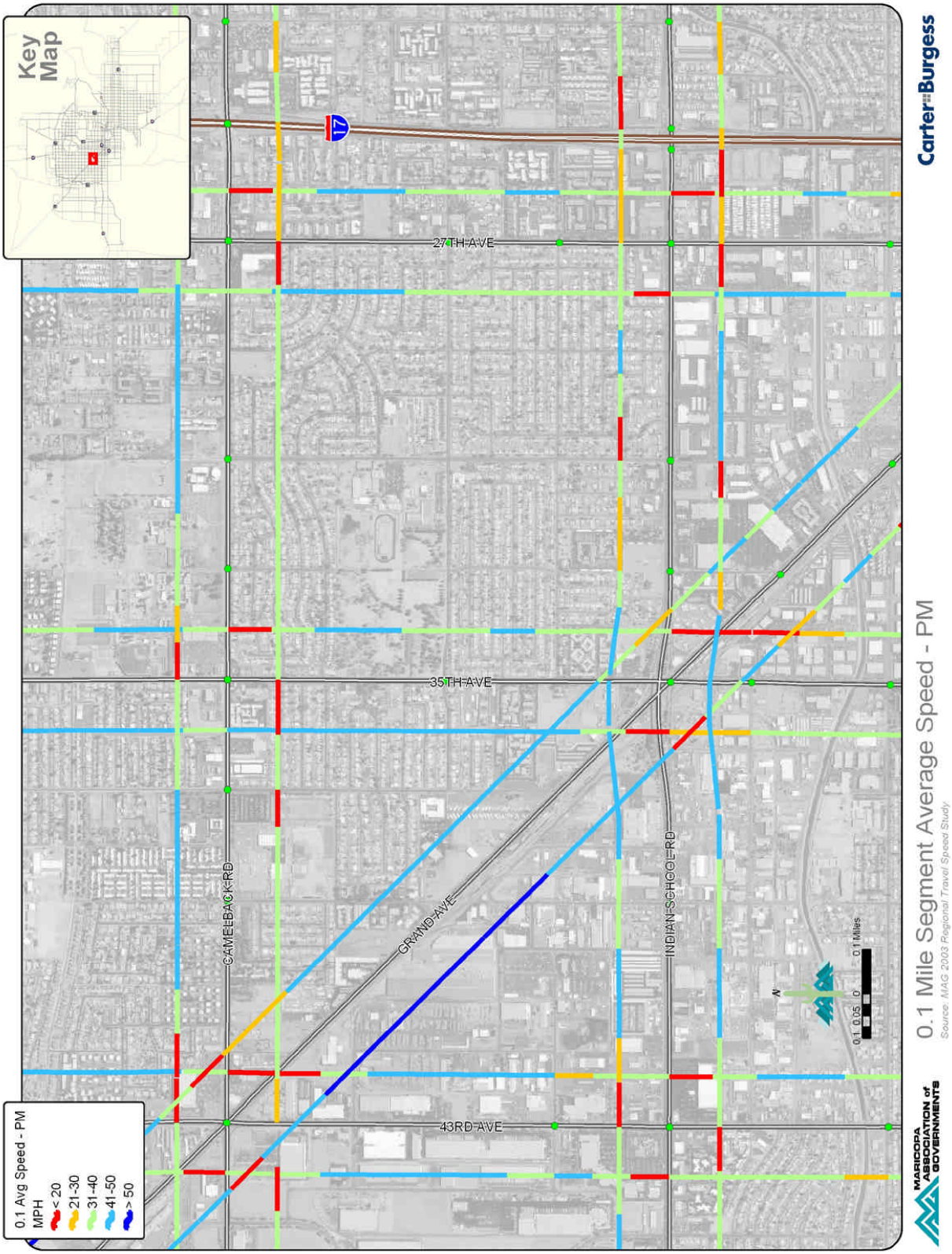


Figure 5 – 0.1 Mile Segment Average Speed – PM (Detail)



The data can further be summarized by jurisdiction for various measures of effectiveness. **Figures 6** and **7** illustrate the resulting average speed by jurisdiction for arterials and freeways, respectively. Only those jurisdictions with functionally classified freeways are included in Figure 7.

Figure 6 – Average Arterial Speed by Jurisdiction

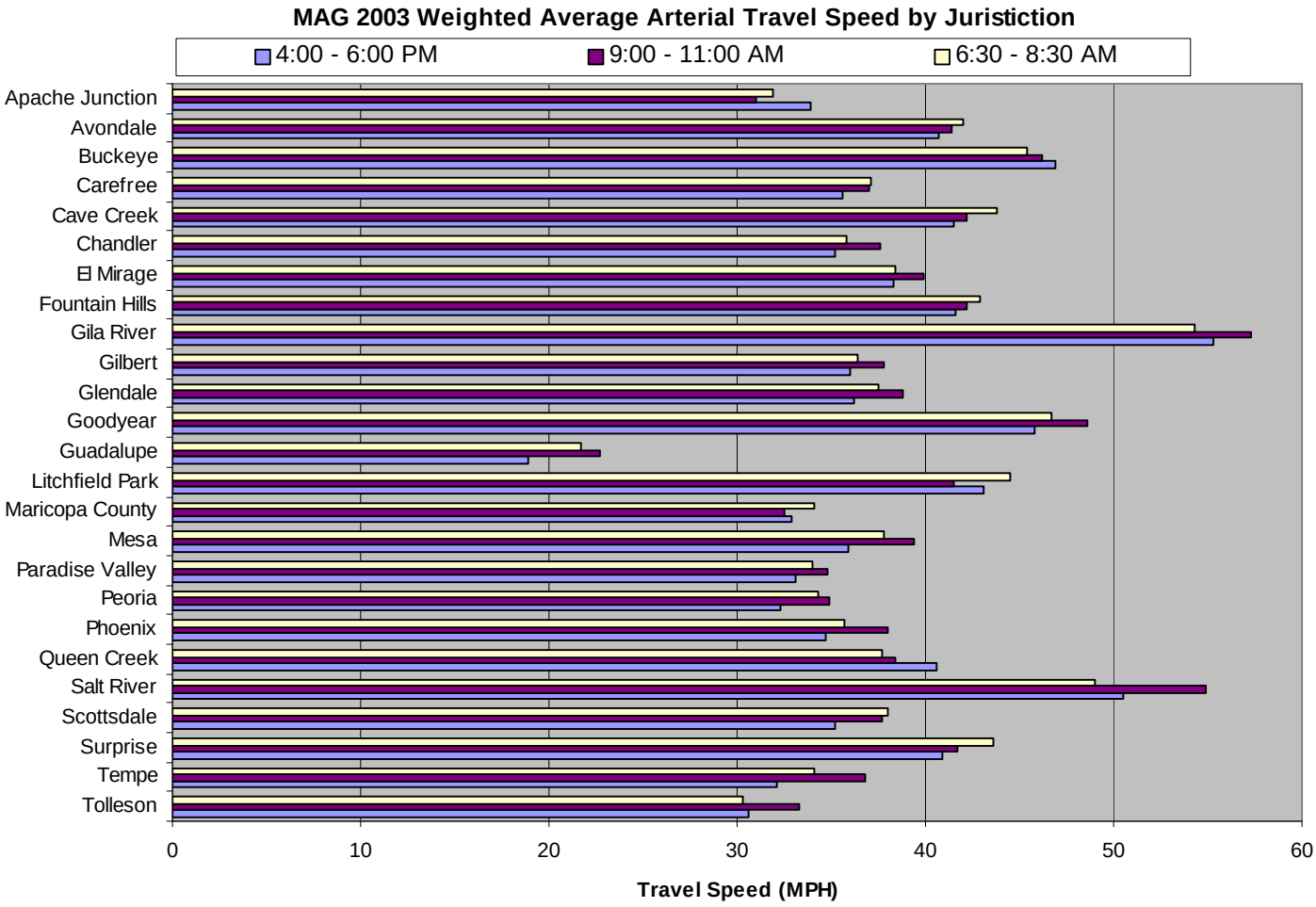
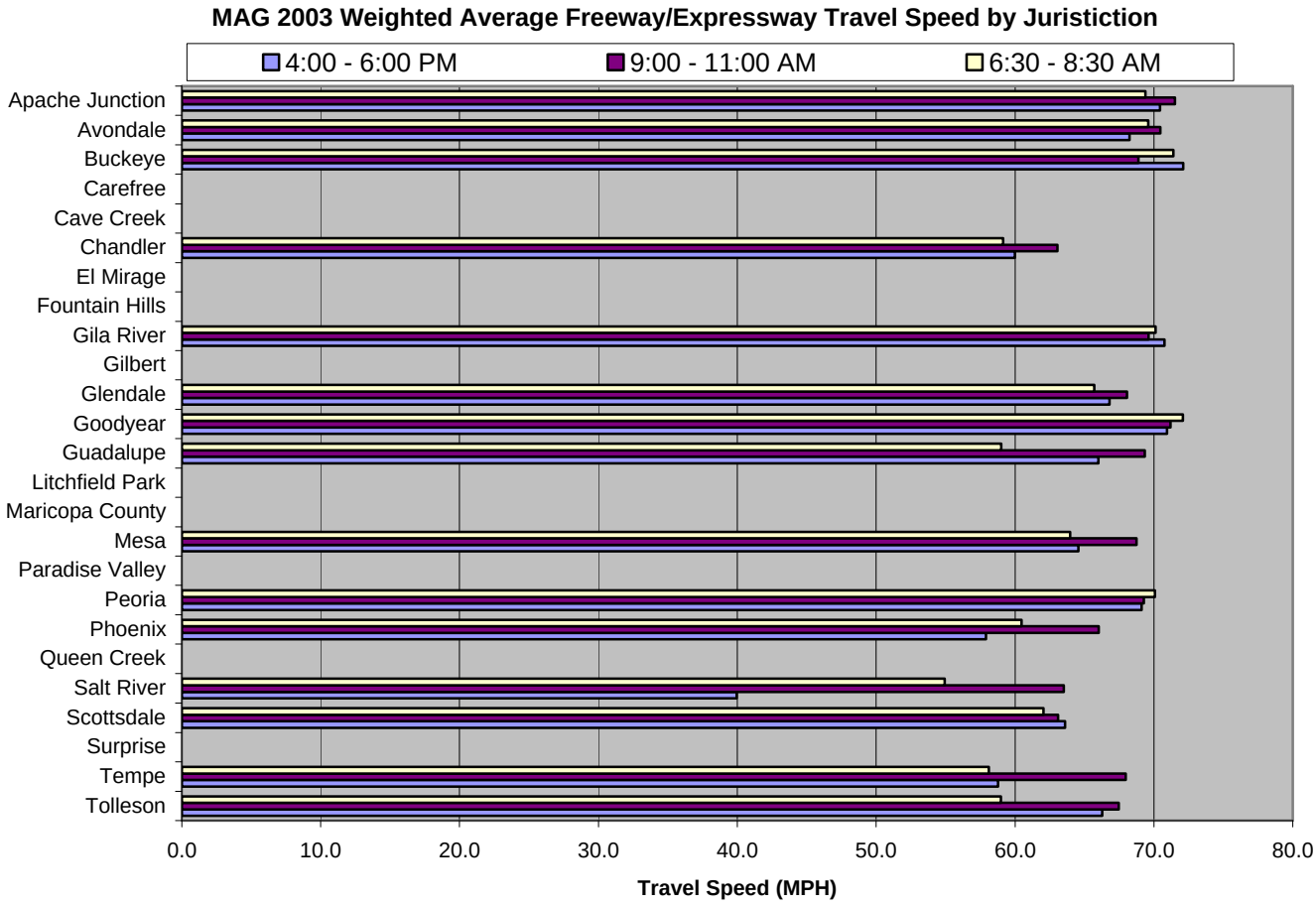


Figure 7 - Average Freeway Speed by Jurisdiction



In order to differentiate between congested roadways and roadways with low speed limits, an additional method for illustrating the data was incorporated into the 2002-2003 Travel Speed Study. This method uses a ratio of actual travel speed to posted speed limit and is referred to as the Congestion Index (CI). The average arterial and freeway CI by jurisdiction is shown on **Figures 8** and **9**. Only those jurisdictions with functionally classified freeways are included in Figure 9.

Figure 8 – Average Arterial Congestion Index (% Posted Speed) by Jurisdiction

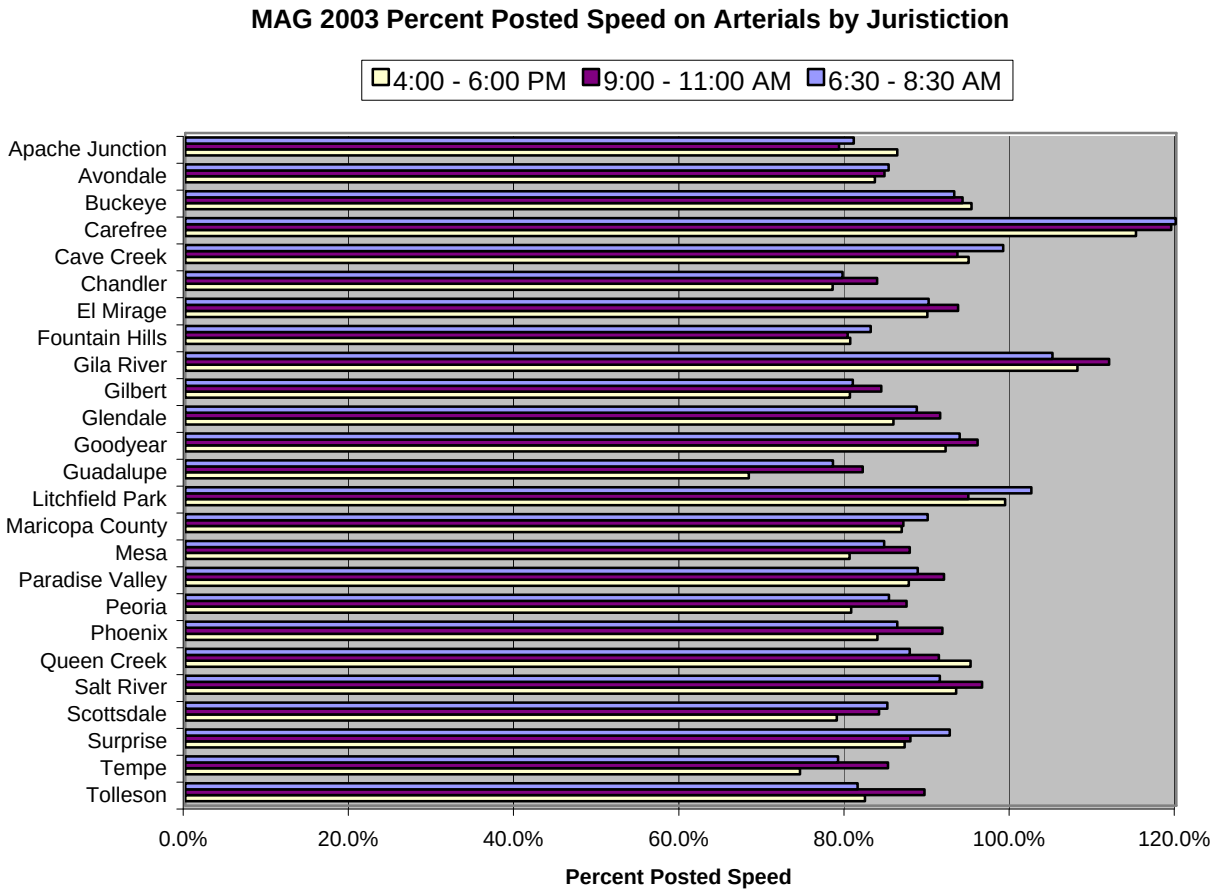


Figure 9 – Average Freeway Congestion Index (% Posted Speed) by Jurisdiction

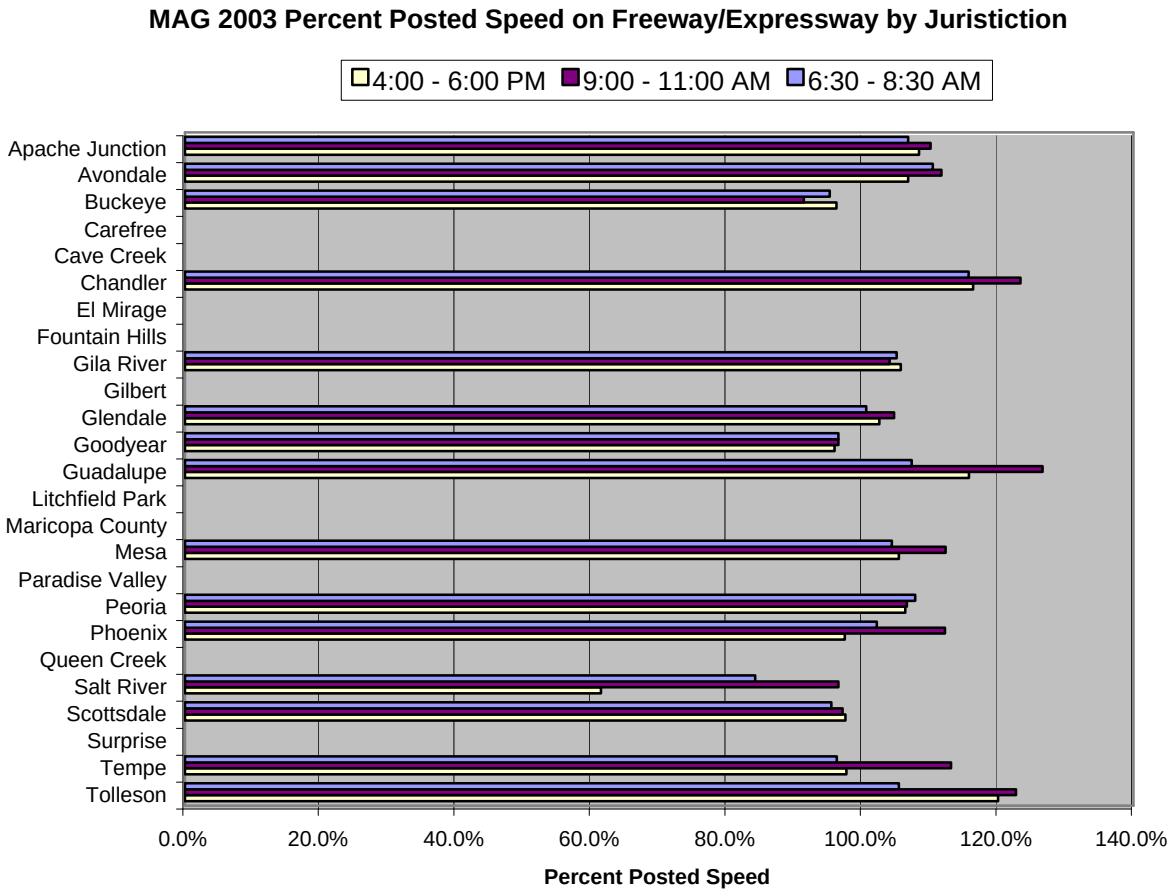
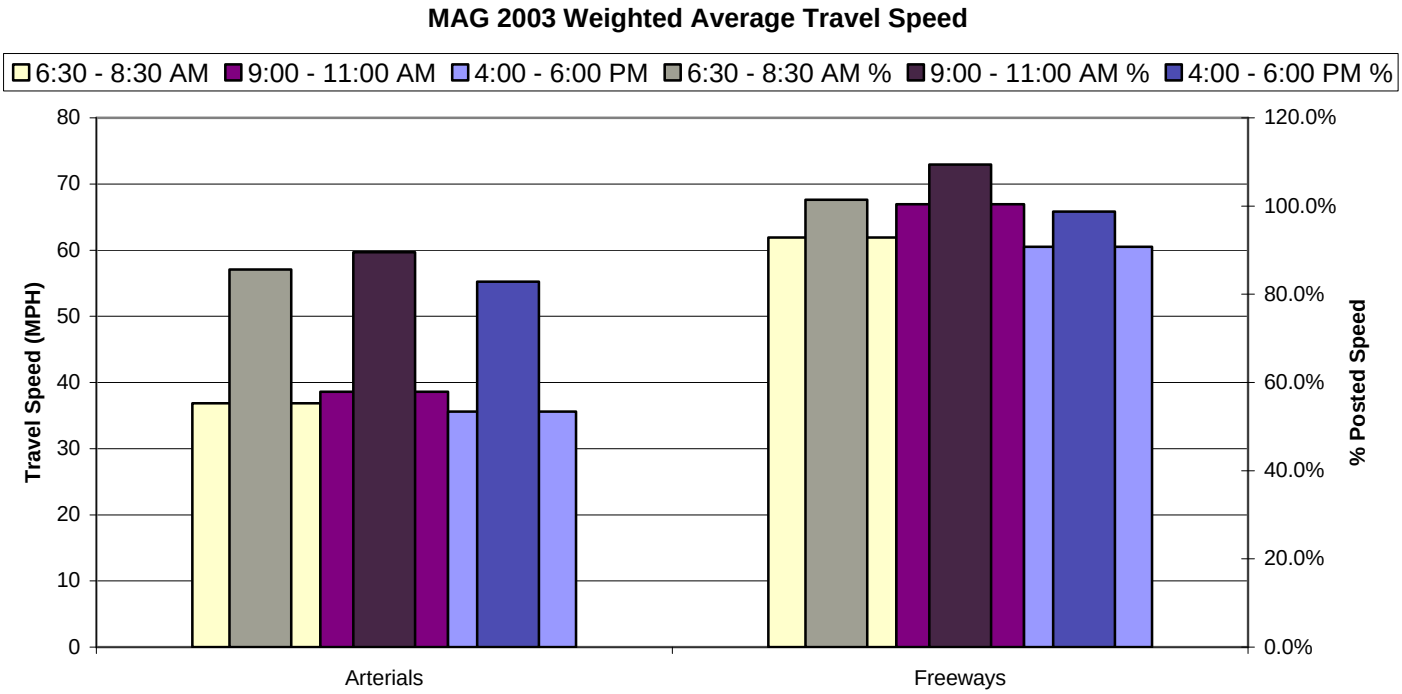


Figure 10 provides an overall summary for the speed and congestion index of all arterials and freeways included in the 2003 study. The solid colors, or shell to the histogram represent the average speed on the respective facility type by time period. The inner shape is the corresponding percent of the posted speed reference to the scale on the right. It illustrates the speeds on the arterials vary by about 3 mph through the day and similarly, the freeways have a range of approximately 5 mph.

Figure 10 - Average Travel Speeds and Congestion Index



1.3 Historical Comparisons

The historic results from the 1979, 1986, and 1993 were geocoded using the linear reference network created. This effort allows multiple comparisons and queries in GIS. **Table 2** illustrates the changes in speed between the Cities previously tabulated in historic studies.

Table 2 – Average Speed between Central Business Districts
Average PM Peak Period/Peak Direction Speed
Between Central Business Districts[1], 1966 to 2003[2]

	Speeds in Miles per Hour							Change in Speeds		
	1966	1970	1976	1979	1986	1993	2003	1966 to 1993	1966 to 2003	1993 to 2003
Glendale - Scottsdale	33.4	31.6	29.6	26.5	26.8	25.1	40.1	-8.3	6.7	15.0
Phoenix - Glendale	24.0	26.2	23.0	23.4	22.6	24.6	21.2	0.6	-2.8	-3.4
Phoenix - Scottsdale	25.3	27.1	22.1	26.5	22.8	28.4	32.0	3.1	6.7	3.6
Phoenix - Tempe	25.8	28.4	25.1	28.3	24.4	32.7	34.2	6.9	8.4	1.5
Tempe - Scottsdale	28.5	24.2	25.0	23.9	17.0	20.6	27.3	-7.9	-1.2	6.7
Tempe - Mesa	32.0	30.7	25.7	25.0	19.6	29.3	25.1	-2.7	-6.9	-4.2

[1] CBD Locations:
Glendale-Glendale Avenue and 59th Avenue
Mesa-Main Street and Center Street
Phoenix-2nd Avenue and Washington
Scottsdale-Scottsdale Road and Indian School Road
Tempe-University Drive and Mill Avenue

[2] Speeds for 1966, 1970, 1976, 1979, 1986 and 1993 are from the *1993 Study of Travel Speed and Delay in the MAG Region*.

2.0 Introduction

It is necessary for metropolitan planning organizations (MPO) to maintain an accurate, up to date regional transportation model in order to conform with State and Federal regulations for air quality and transportation projects. MPO's update and calibrate their models using current information on the roadway network, area development, and other relevant characteristics. The Maricopa Association of Governments updates their travel time and speed data periodically.

The primary purpose of this year's 2002-2003 Travel Speed Study was to calibrate and validate the regional planning model. The area encompassed by MAG is currently within air quality attainment levels, but has been bordering on non-attainment. The EPA required validation of the model as part of the review process. A secondary purpose was to compare this year's data with data from previous years to identify trends in congestion and travel time in order to identify problem locations for possible improvements.

The 2002-2003 Travel Speed Study data can be used for a variety of additional uses. With the travel speed information organized in a GIS system including other data such as facility and area type, number of lanes, etc., queries can group data by city for use in individual planning processes. The digital video in some cases can substitute for field visits, saving time and money for the MPO and City staffs. The database can be used for background information for street improvements, signal timing, signing and pavement marking, school zone issues, and other transportation related projects.

The following report describes the 2002-2003 Travel Speed Study.

- Section 3 focuses on the methodology and includes a set of assumptions and caveats, definitions for terms used throughout the report, the method for route selection, and the process used to actually collect and manipulate the travel speed data. Information is provided regarding quality control, data analysis, data aggregation, and problems encountered during the data collection process.
- Section 4 documents the results of the data collection showing various aggregations such as travel speeds by functional class, travel speed by jurisdiction, and other relevant combinations.
- Section 5 focuses on intersection delay.
- Section 6 documents the historical trends and changes in travel speeds and delays in the regions.

3.0 Methodology

This section details the approach followed including the selection of routes, data collection equipment and training, mapping, travel time periods, quality control, data analysis, summary of data, and problems encountered.

3.1 Definitions and Data Dictionary

Several terms are used throughout this report and are defined here for clarification.

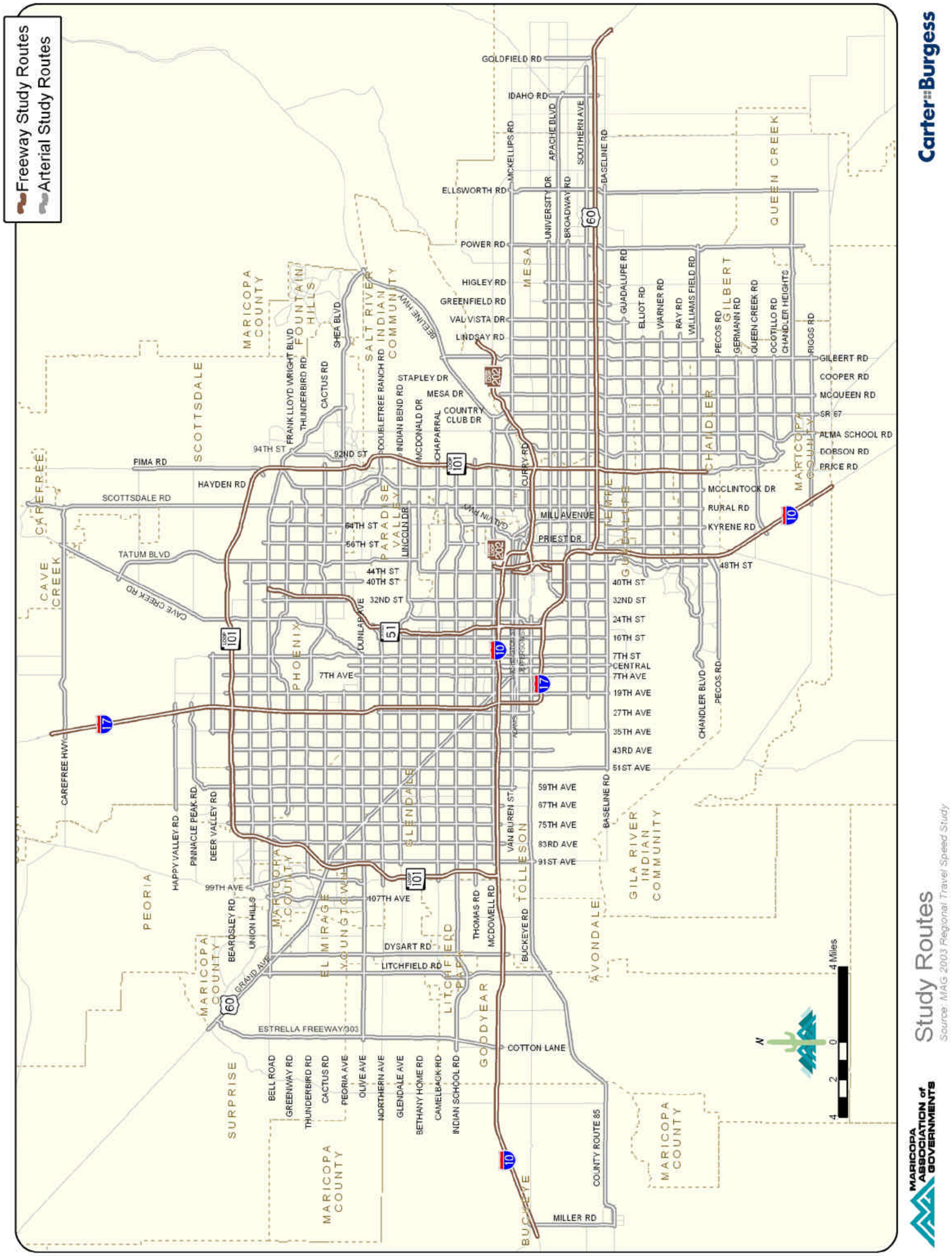
Table 3 - Glossary

Term	Definition
Afternoon Peak Period	The time period from 4:00 PM to 6:00 PM on a typical weekday
Observed Queue Length	This is the distance between the test vehicle and the intersection from the point where the speed of the test vehicle drops below 3 mph.
Congestion Index	The ratio of the actual speed to the posted speed limit.
Control Delay	Stopped delay times 1.30 (see Sec 5.1)
Free Flow Speed	Speed Limit or weighted average speed limit. Weighted by length of speed zones where the speed limit changes between intersections.
Geo-referenced Digital Video	Digital video of selected runs that are geo-referenced to the GPS points to allow indexing and viewing of the video accurate in time and location.
Mean Running Speed	Speed calculate from the time the vehicle is traveling at > 3 MPH
Mean Travel Speed	The distance divided by the mean travel time of several trips.
Midday Off Peak Period	The time period from 9:00 AM to 11:00 AM on a typical weekday
Morning Peak Period	The time period from 6:30 AM to 8:30 AM on a typical weekday
Peak Period	Two hour time period
Space Mean Speed	Speed calculated from the distance traveled over the time to travel that distance
Spot Speed	The instantaneous measure of speed at a specific location on a roadway.
Stopped Delay	Number of seconds a vehicle is below 3mph with a given segment.
Theoretical Travel Time	Time it takes for a vehicle to travel a given section of roadway at the posted speed limit.
Time Mean Speed	The arithmetic average of 1 second GPS speed within the segment.
Time Period	A shorter time interval within one of the two hour periods

3.2 Route Selection

The 2002-2003 Study included most of the higher volume arterials and all freeways/HOV lanes within the study area. The included routes are shown in **Figure 11**. All signalized intersections on these routes were included in the study for delay calculations as well. All roadways included in previous studies were included in this time, as well as additional roadways.

Figure 11 - Study Routes



3.3 Project Methodology

The 2002-2003 Travel Speed Study was conducted similarly to previous studies including performing travel time studies with the floating car method, but this years study was enhanced in the data collection, data management, and analytical methods. The study was conducted so that results could be compared with the historical results of the 1979, 1986, and 1993 Travel Time Studies in order to identify trends and changes in the roadway network and characteristics; however, additional data and advancements in data collection methods allowed for more detailed traditional analyses as well as analyses that had previously not been performed.

First, the roadways were mapped to establish centerlines and record relevant roadway features. The geographic information system (GIS) utilizes a linear reference system (LRS) for the basis of all roadway and travel speed data. Features and data within a linear reference system use position along a route instead of a x,y coordinate system. The route features contain measures or distance along the route. For this travel time study the route network contains all streets included in the study. Details and illustrations of the LRS are included in the Appendix. After mapping all routes, the travel time runs were collected. Details on the data collection are found in the following section.

A 15-minute headway was used between each run in order to document speed variation over the two-hour morning and afternoon peak periods. Intersection delay was calculated for all signalized intersections within the study area. Delay calculations were provided for through vehicles only. No analyses were conducted for turning movements. The delay in seconds was then compared with the *Highway Capacity Manual*, Transportation Research Board, 2000, Exhibit 16-2, criteria for level of service for signalized intersections. These criteria categorize vehicle delay into levels of service ranging from LOS A, meaning less than or equal to 10 seconds delay, to LOS F, meaning more than 80 seconds of delay.

The location of the survey vehicle in the queue was measured for each approach of each intersection. A test vehicle was determined to be in a queue if the speed of the vehicle dropped below 3 mph. The test vehicle may not have been the last vehicle in the queue, since additional cars could have joined the queue after the test vehicle. Because of this, the measured queue length does not represent the maximum queue, but can be used as a representative measure.

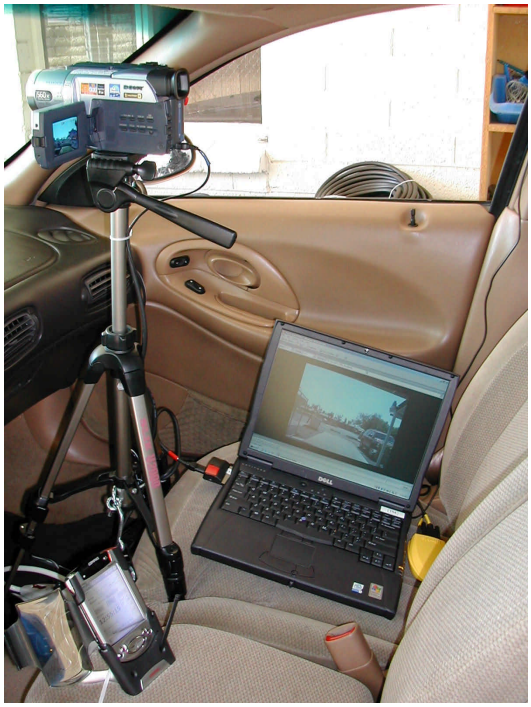
Previous travel time studies documented the observed speed on roadways without regard to the posted speed limit. This method may indicate slow speeds when in reality, traffic may be traveling according to a low posted speed limit. In order to differentiate between congested roadways and roadways with low speed limits, a new method for illustrating the data was incorporated into the 2002-2003 Travel Speed Study. This method uses a ratio of actual travel speed to posted speed limit called the Congestion Index (CI). A CI of 1.0 or greater indicates free flow speed, where traffic is traveling at the speed limit or higher. Municipalities can define levels of CI to indicate

free flow, average flow, and congested flow. This information can be used in the planning process to better appropriate funds for needed improvements.

This study for the first time uses digital video for quality control referenced digital video in GIS to review travel time runs. All data collected as part of this project was incorporated into MAG's GIS system. A user can now click on any point along a corridor and view the digital video from a travel time run, starting at that point. This enhancement allows the user to view the exact conditions encountered by the technicians during their travel time runs and provides benefits including: identification of problems, illustration at public meetings, and use in future projects.

3.4 Data Collection

3.4.1 Equipment and Training



Mapping was conducted using a Trimble PRO-XRS GPS unit with real-time differentially corrected data and sub-meter accuracy. The GPS unit was attached to a test vehicle and roadway features were coded using software on a laptop computer.

Travel time runs were conducted using Trimble Pathfinder Pockets. These units are significantly less expensive than the Trimble PRO-XRS and provide accuracy to 10-feet after being post-processed differentially corrected. The GPS data was collected and stored on personal data assistants (PDA) using Microsoft operating system and customized data management program.

The Carter & Burgess managers trained and rode with technicians on example routes. The training occurred over two days, and each technician was tested by the managers before being permitted to work on the project. Training consisted of an overview of the project, the equipment being used, the floating car method for travel time runs, and safety.

3.4.2 Procedure

The first step in the study process was to map the roadways using GPS equipment to establish centerlines and code relevant roadway features. Centerlines were mapped by driving in one direction and using an offset distance from the travel lane to code the centerline. Features documented in the mapping process included: intersection control (**Figure 12**), speed limits (**Figures 13 and 14**), number of lanes (**Figures 15, 16 and 17**), school zones limits (**Figure 18**), and construction areas. Other elements were coded in GIS using data provided by the MPO. Those included jurisdictional

boundaries (**Figure 19)**, area type (**Figure 20**), and facility type (**Figures 21, 22 and 23**). The area and facility type were used to compare similar roadways, speed limits and school zone speed limits were used to calculate the Congestion Index to determine whether roadway segments were congested, intersection control was collected to supplement the GIS system, and construction areas were noted so that low speeds in these areas could be filtered. The City Limit lines were collected so that information could be organized by City.
Upon completion of the mapping, the travel time runs were collected. The equipment automatically collected location and time data every 1-second. This information was used to calculate speeds and travel times.

For the 2002-2003 Travel Speed Study, data was collected from September 2002 through June 2003. The data was collected on Tuesdays, Wednesdays, and Thursdays, during the morning and afternoon peak, and during the midday off-peak period. Runs were conducted on Tuesday through Thursday because they more consistently represent average conditions. Later in the project, runs were added for the Monday PM and Friday AM period to accelerate the schedule. The study time periods were as follows:

- Morning Peak Period: 6:30 to 8:30 AM
- Midday Off-Peak Period: 9:00 to 11:00 AM
- Afternoon Peak Period: 4:00 to 6:00 PM

Travel time runs were conducted using the floating car method, as was used in the previous studies. The floating car method is described in detail in the Manual of Traffic Engineering Studies published by the Institute of Transportation Engineers. The test vehicle travels within the flow of traffic, passing as many vehicles as pass the test vehicle. In this way, the test vehicle is representing the average vehicle.

Figure 12– Intersection Control

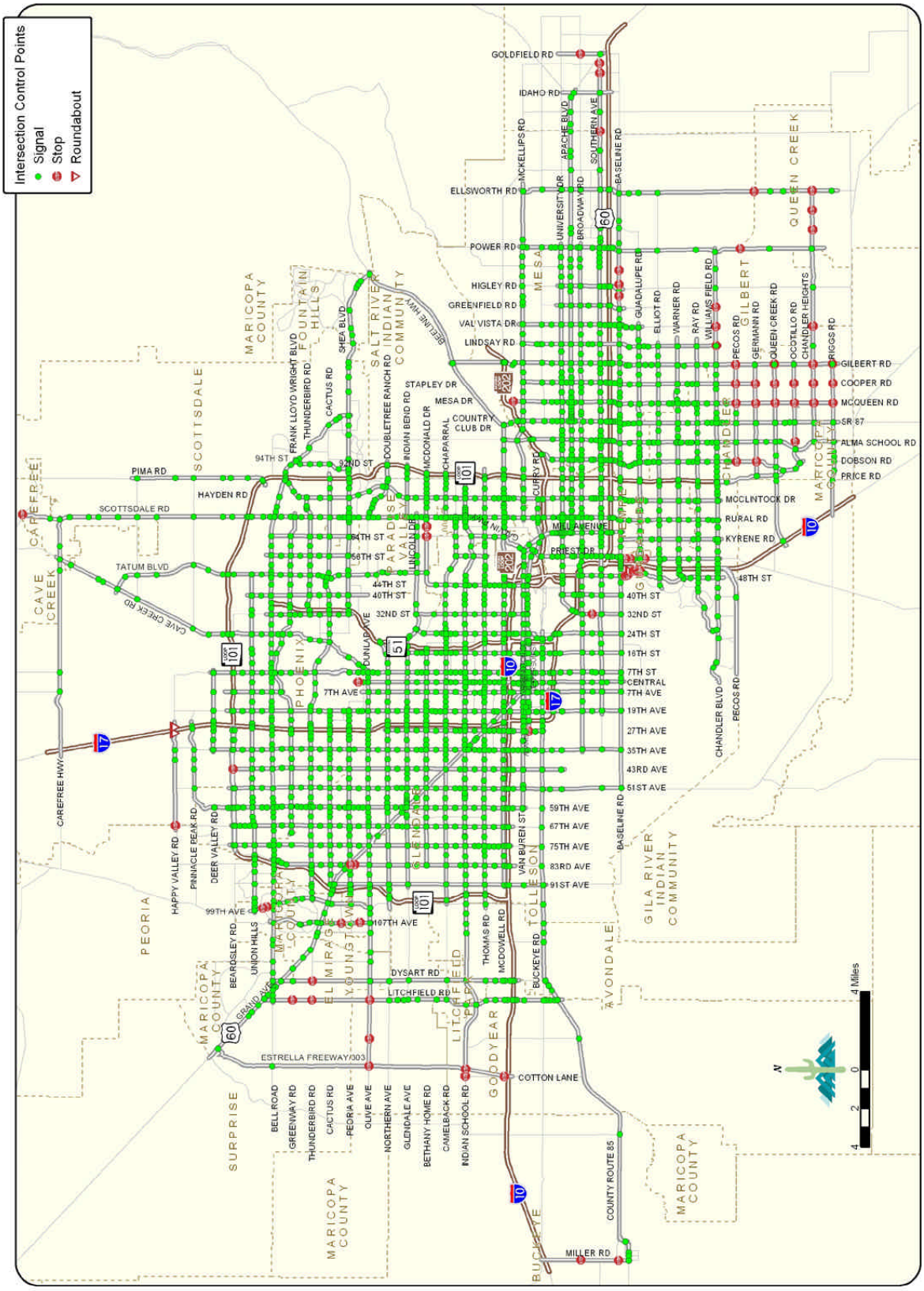


Figure 13 – Posted Arterial Speed Limits

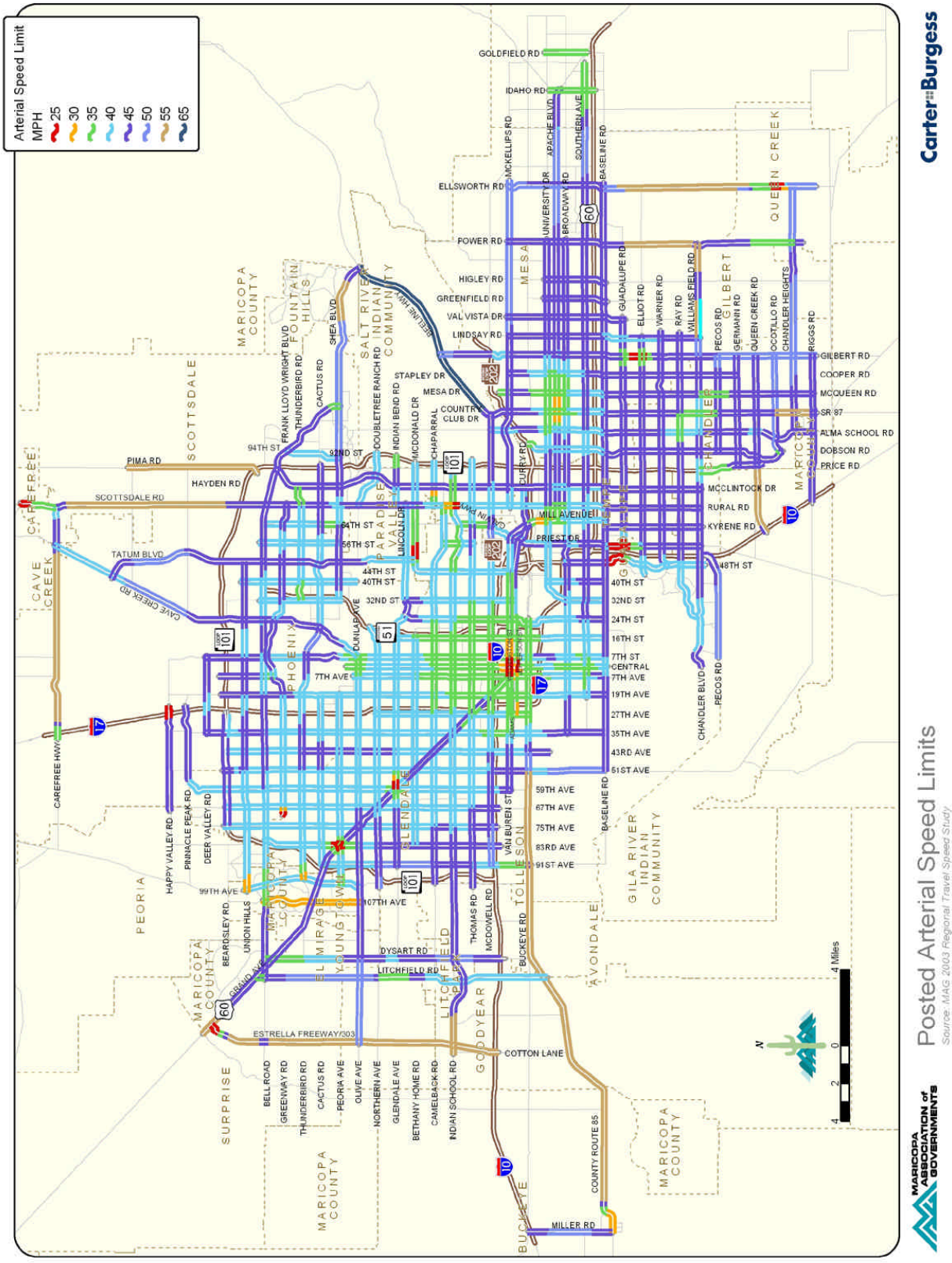


Figure 14 – Posted Freeway Speed Limits

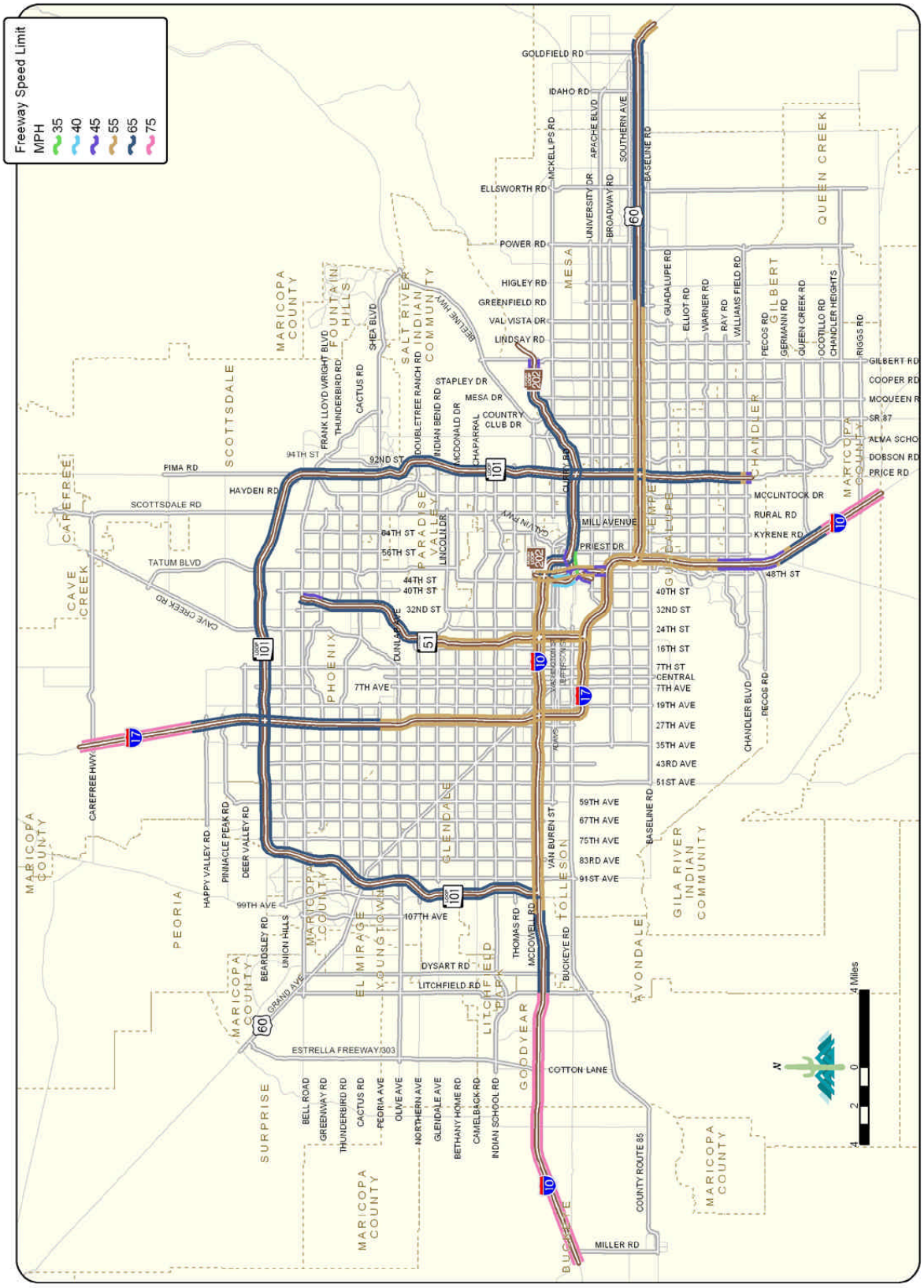


Figure 15 – Arterial Number of Lanes Each Direction

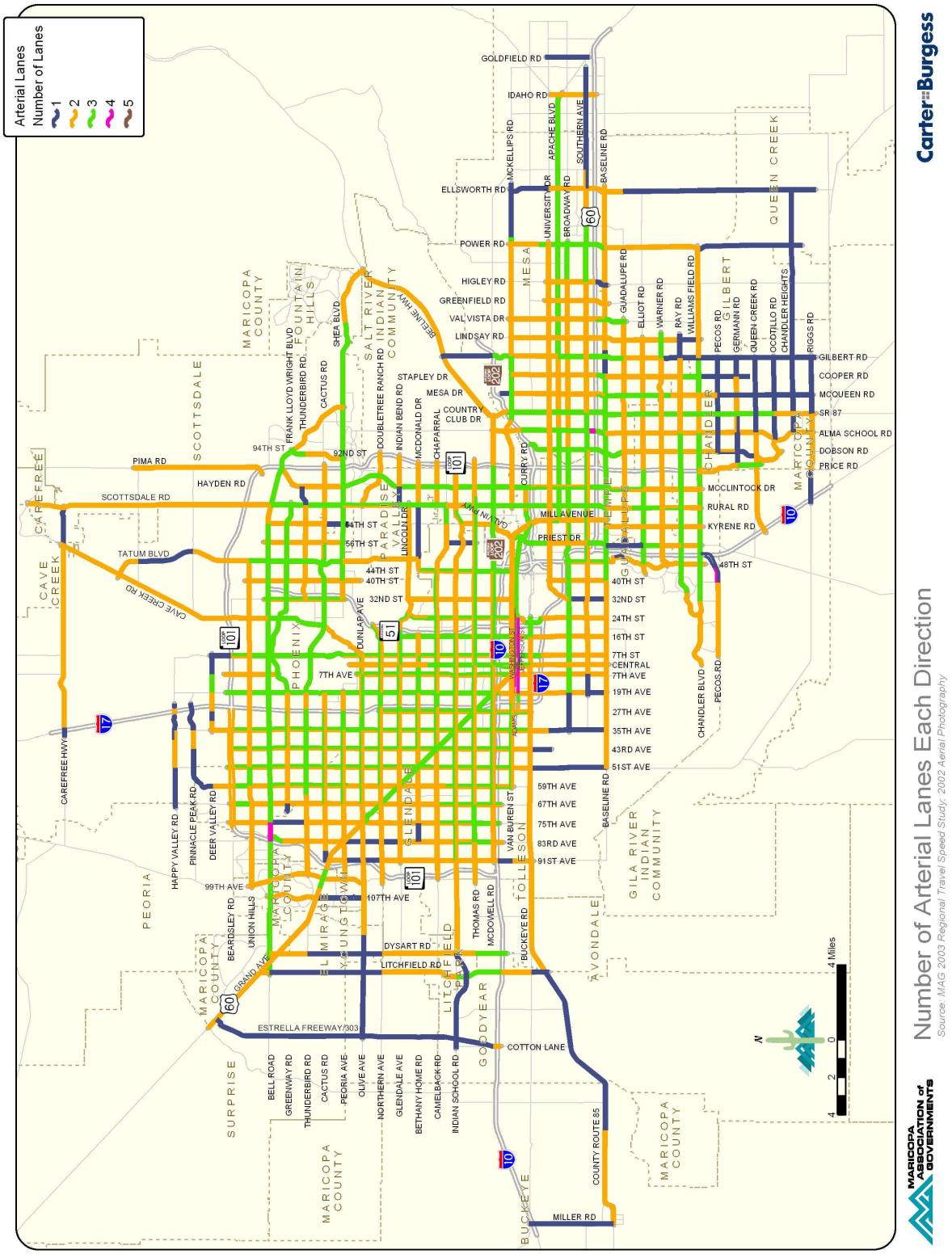


Figure 16 – Number of HOV Lanes Each Direction

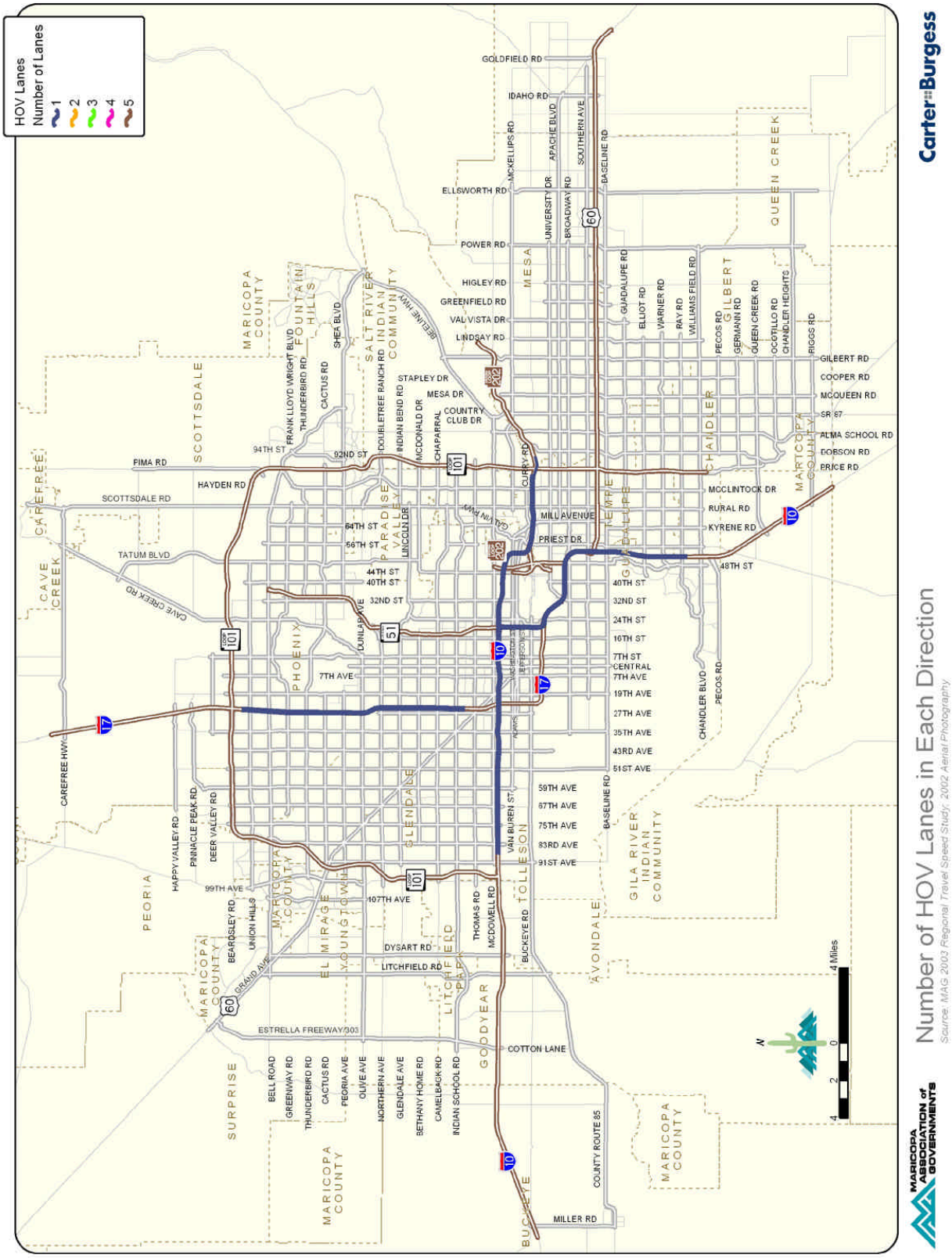


Figure 17 – Number of Freeway Lanes Each Direction

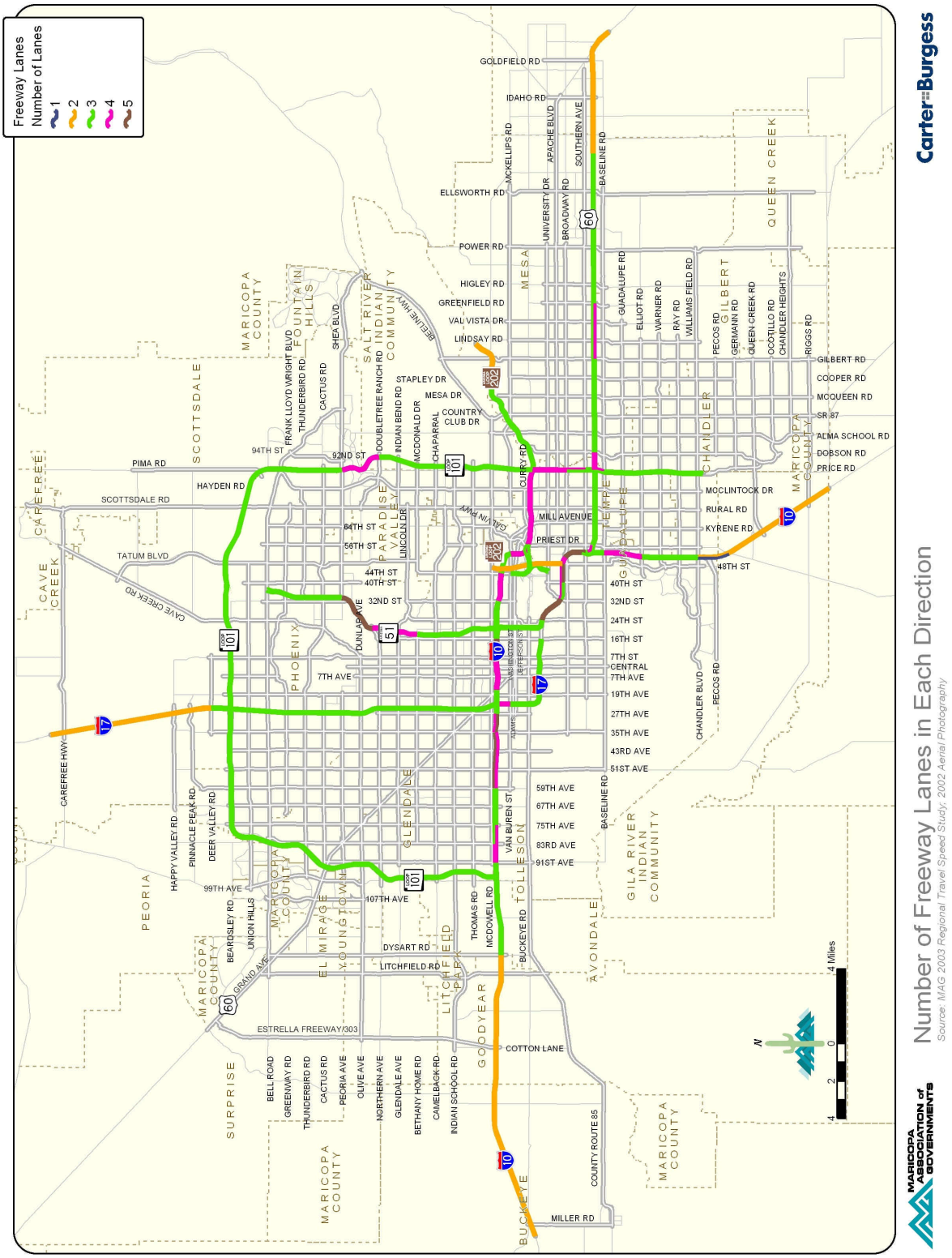


Figure 18 – School Zones

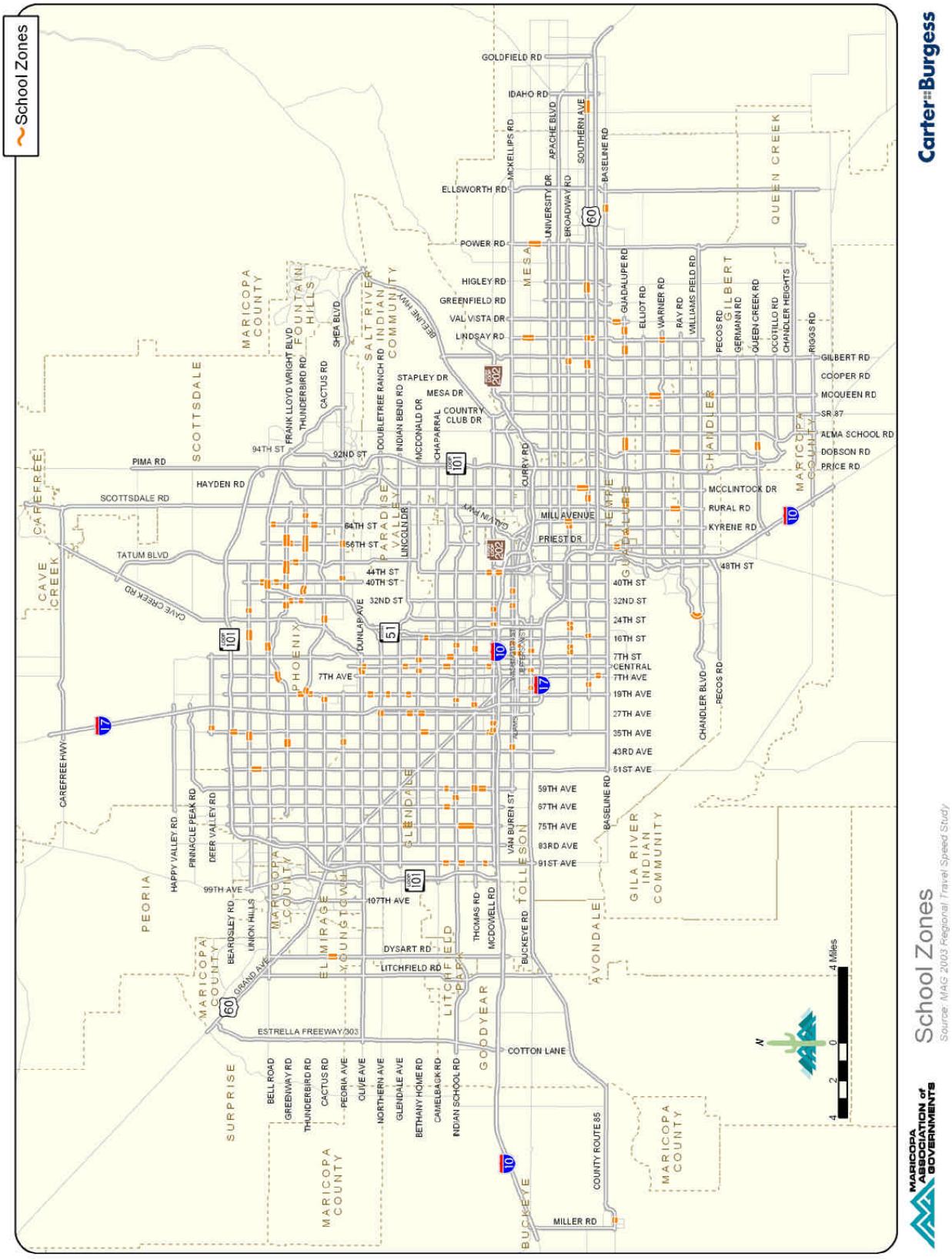


Figure 19 – Jurisdictional Segments

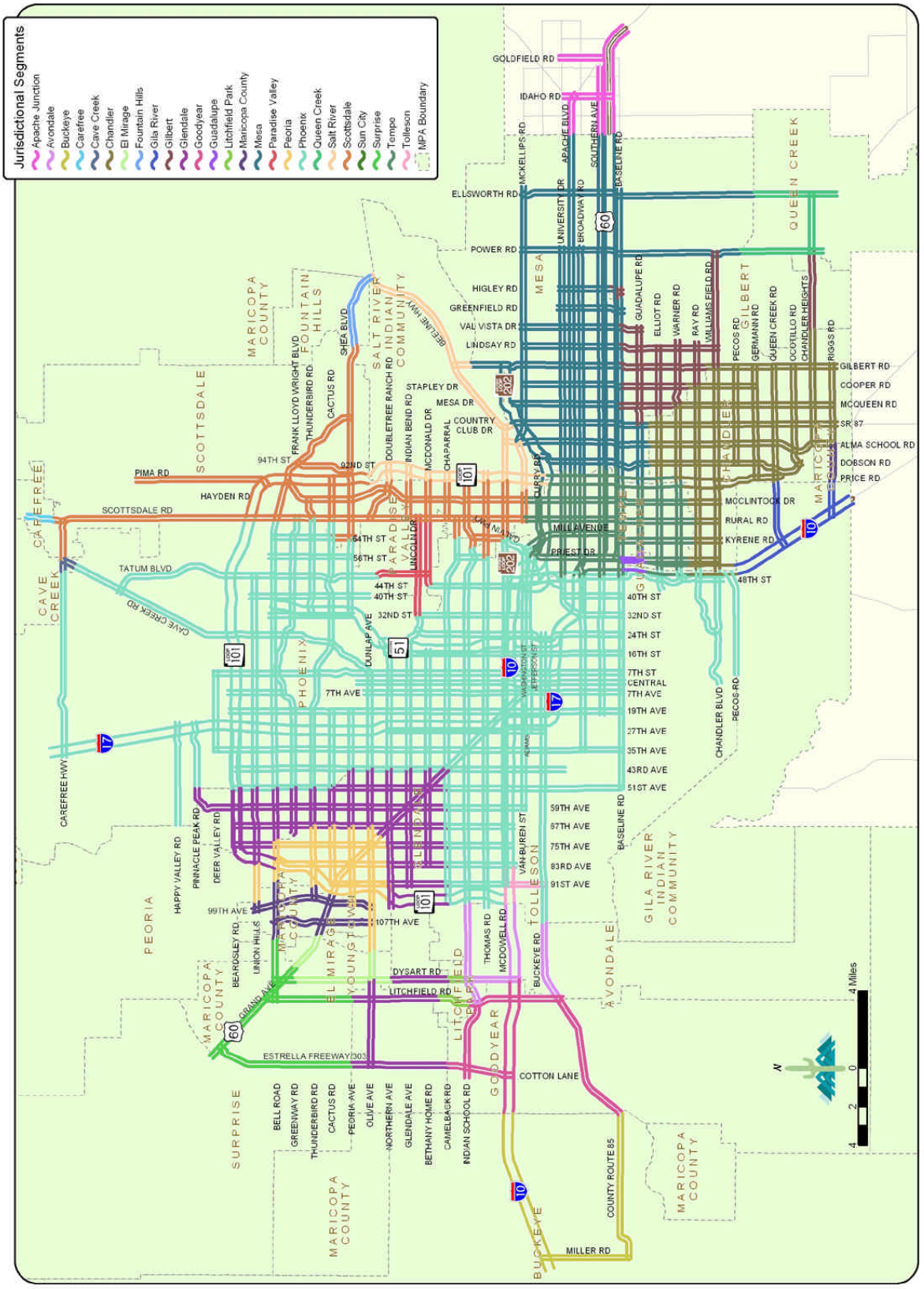


Figure 20 – Area Type

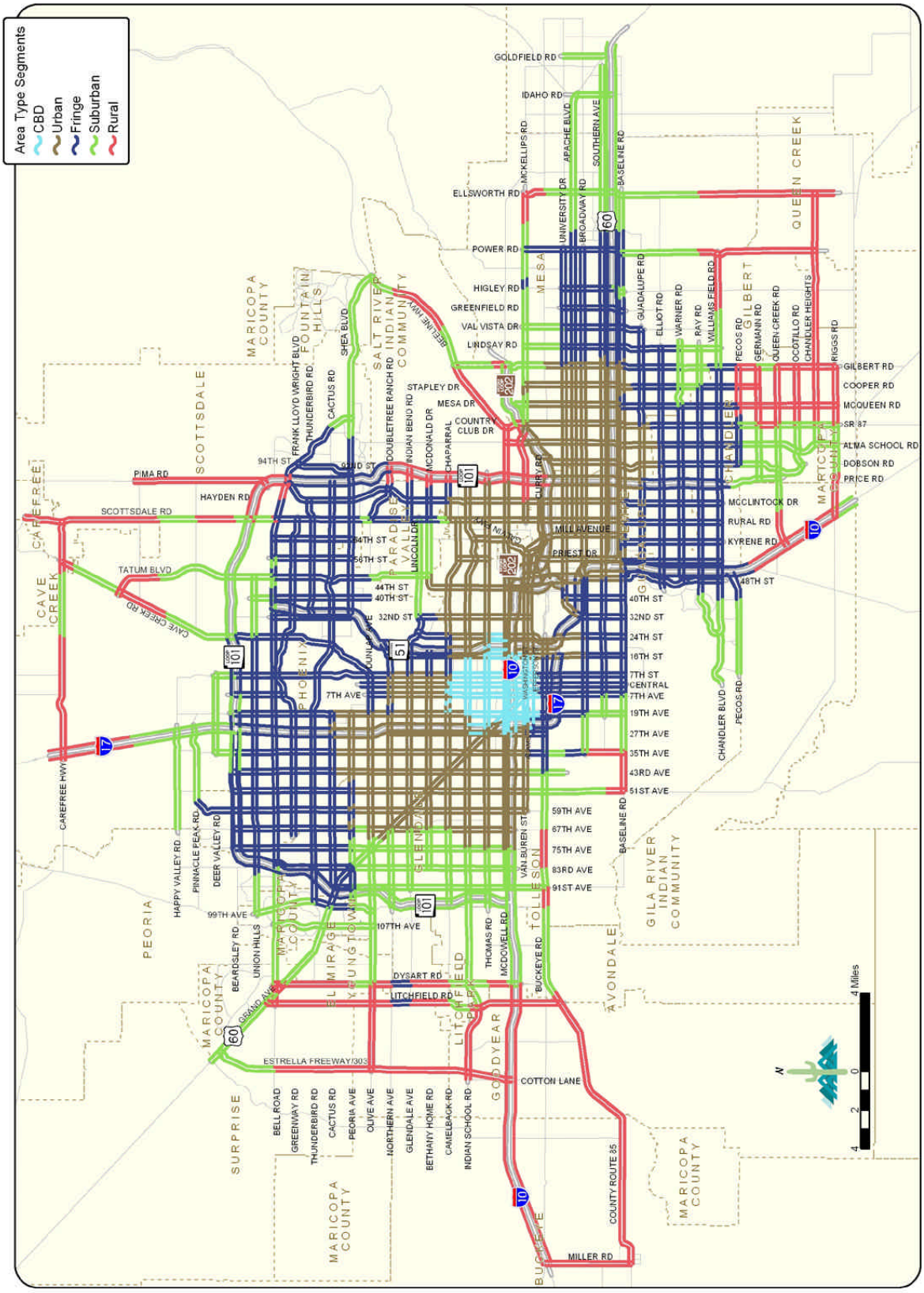


Figure 21 – Arterial Facility Type

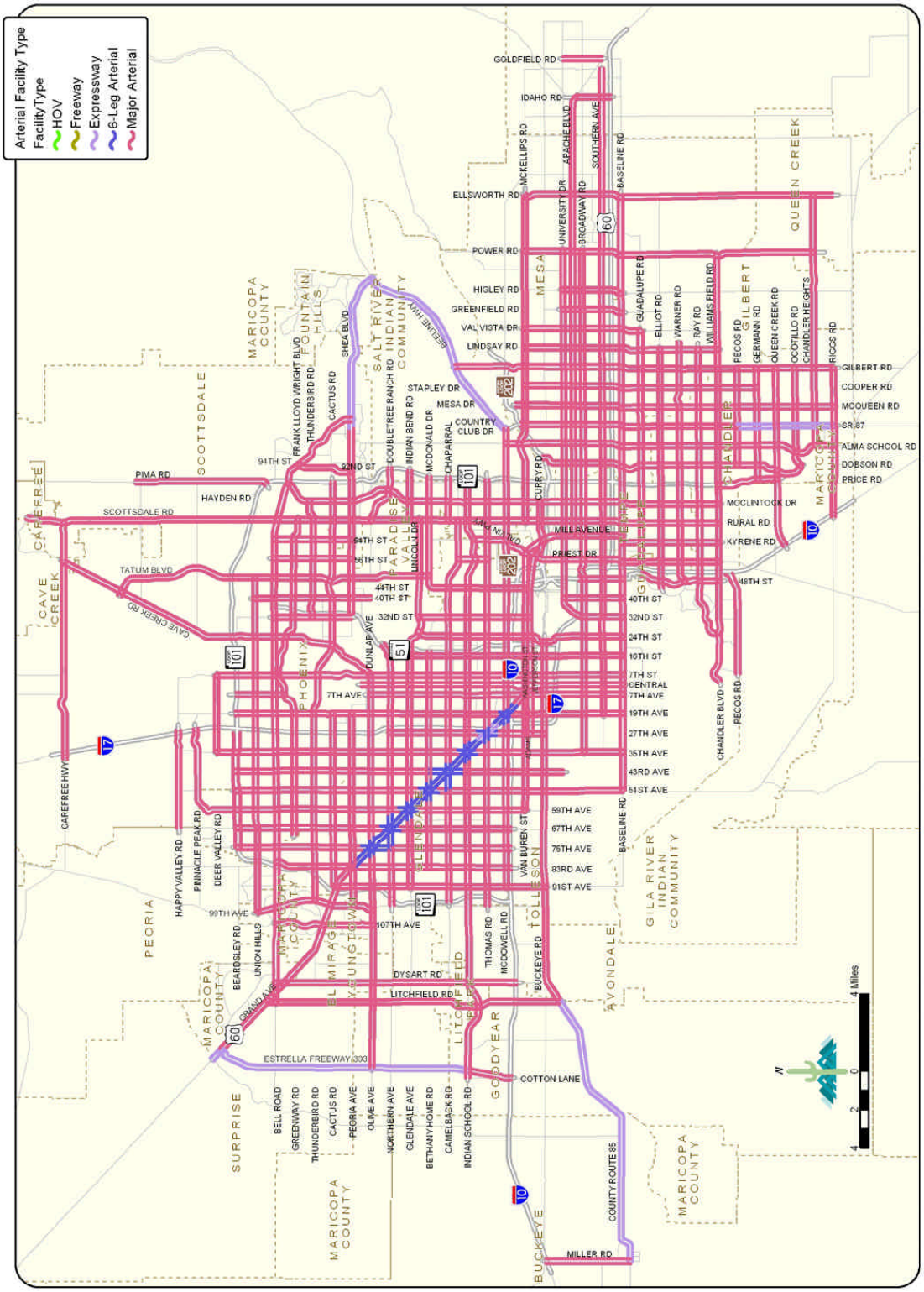


Figure 22 – Freeway Facility Type

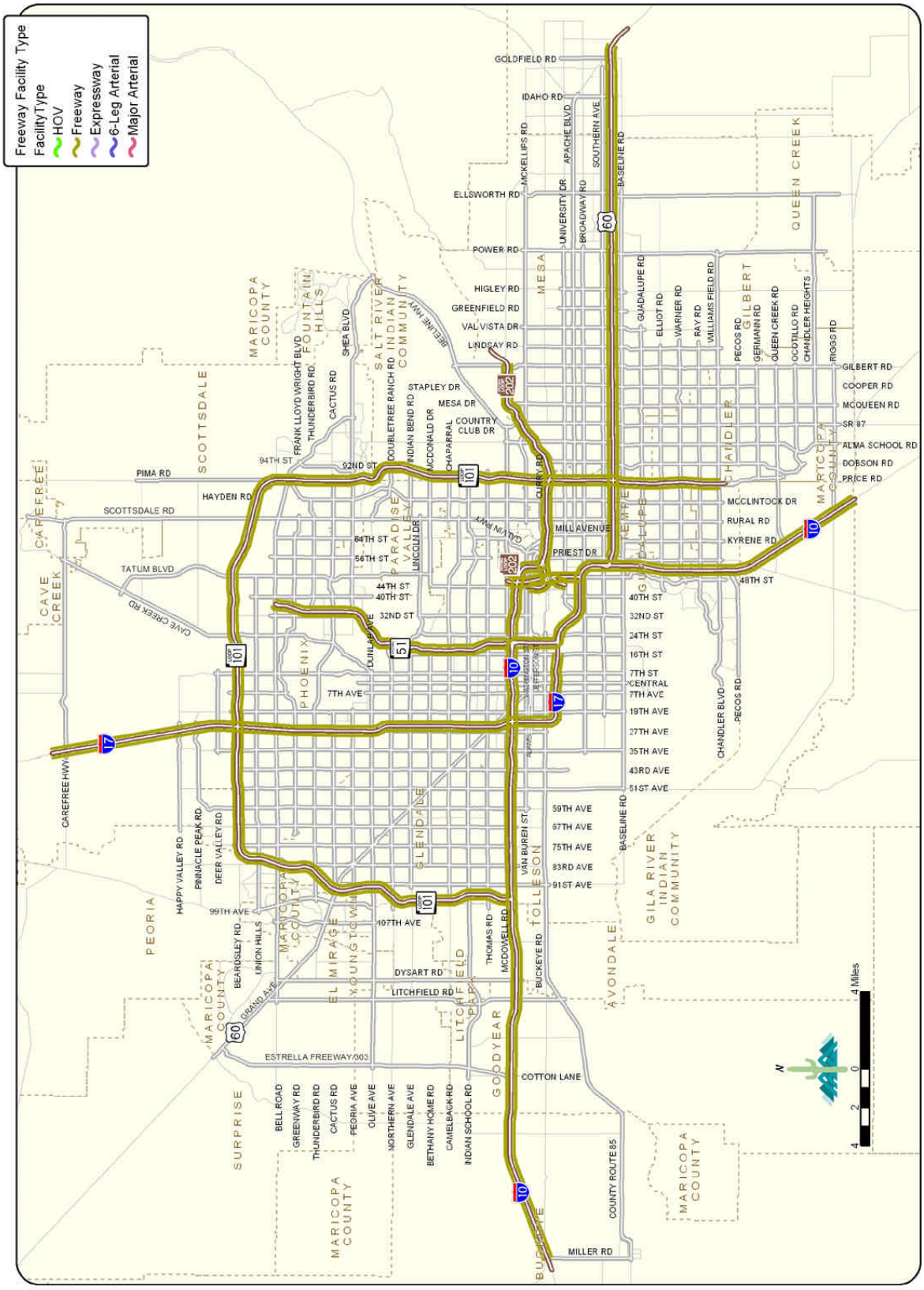
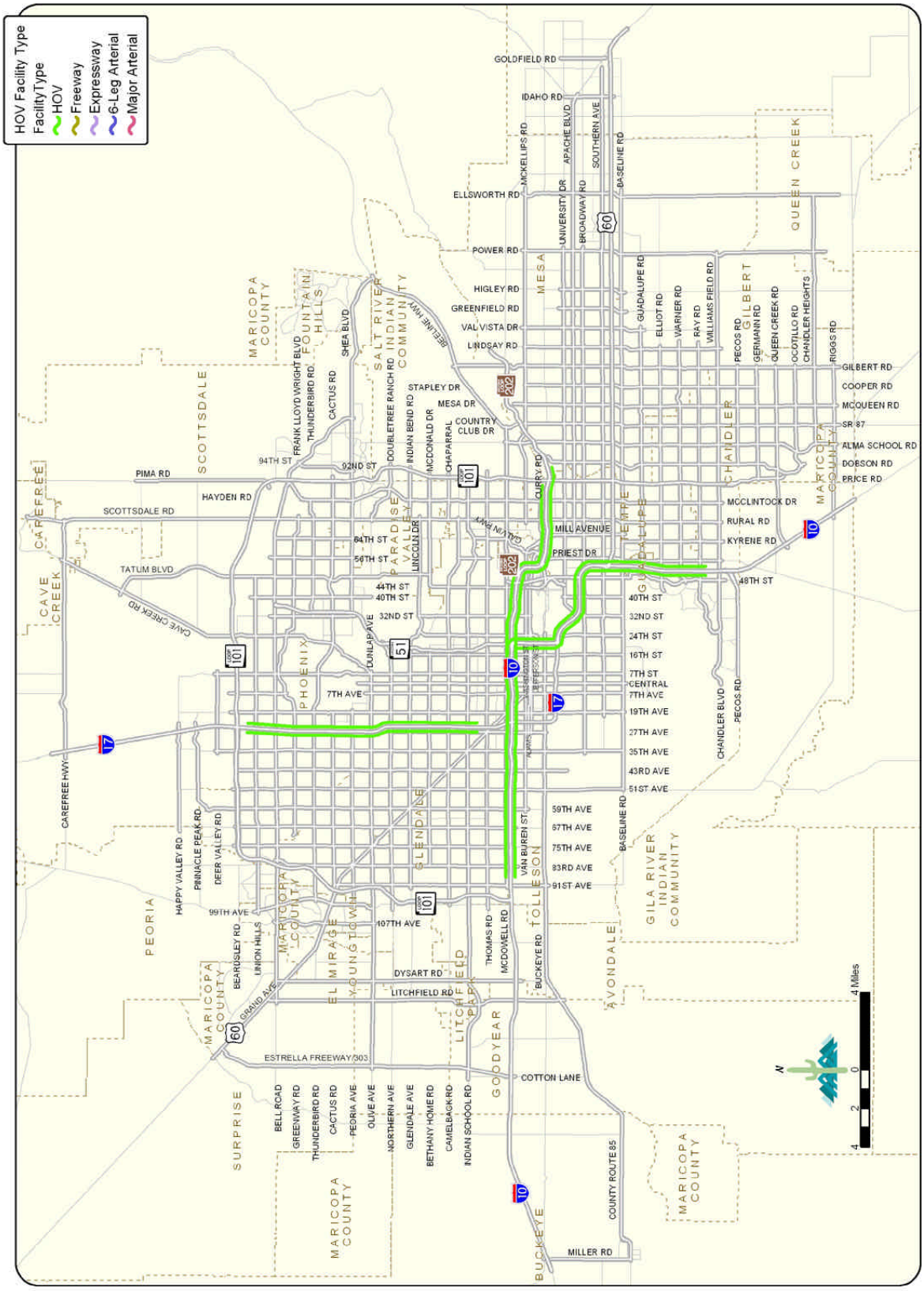


Figure 23– HOV Facility Type



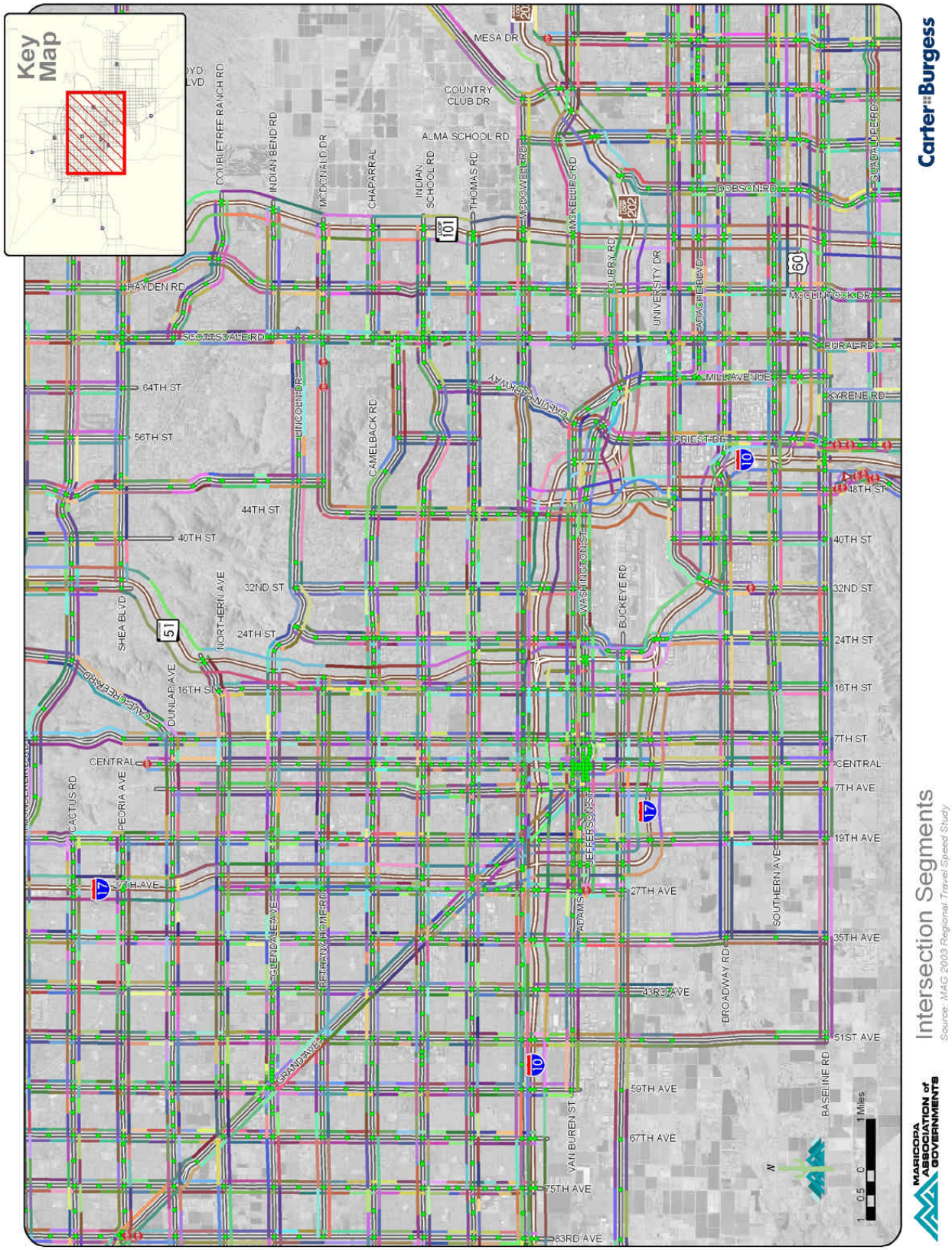
HOV Facility Type
Source: MAG 2003 Regional Travel Speed Study

Travel time runs were conducted on 1,750 centerline miles of routes along all arterials, freeways, and HOV lanes. As shown in **Figure 24**, the roadways were broken down into 5,838 segments between each traffic control device and 38 runs were made on each segment, including 8 runs in each direction during the morning peak, 3 runs in each direction during the midday off peak, and 8 runs in each direction during the afternoon peak, resulting in over 70,000 miles of travel time runs. The number of runs was assigned by the MPO. Each week, technicians produced 180 hours of data. This data resulted in over 12 million data points and 4,000 hours of digital video. When the runs were completed, a statistical analysis was performed to determine the resulting confidence level and error of the data. If the confidence level was at least 85% with a 5 mph error, the runs were considered satisfactory. The 1,750 centerline miles of roadway were divided among the 24 incorporated communities, towns, Indian Reservations, and Maricopa County.

3.5 Data Monitoring and Quality Control

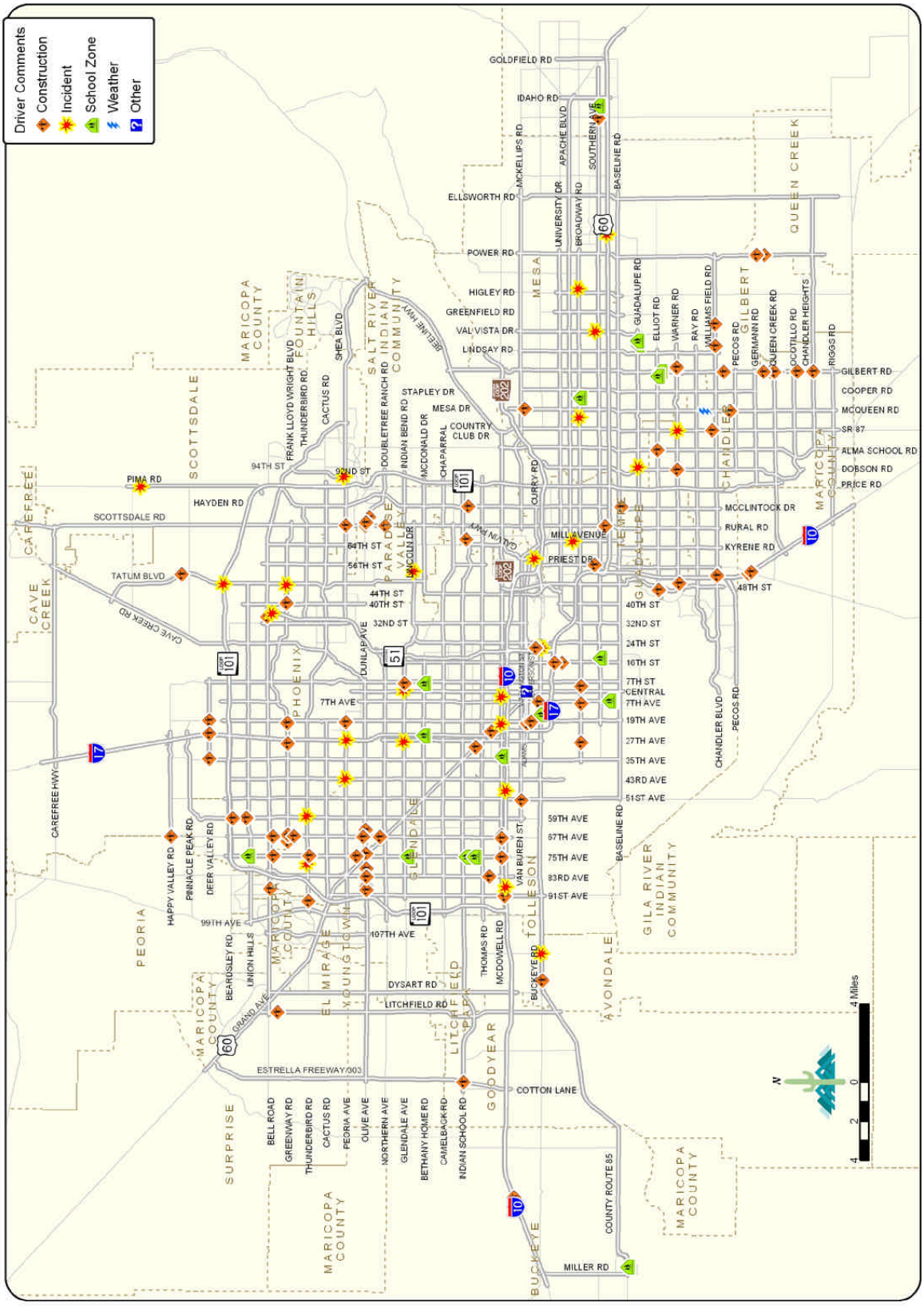
The centerline mapping and travel time runs produced an enormous amount of data. The position information was differentially corrected using an established base station in Scottsdale to bring the accuracy from 50 feet to 10 feet. This corrects any errors that may have occurred in the satellite readings. These files were then exported into a shape file for viewing in GIS. This shape file was used for further quality assurance quality control (QAQC).

Figure 24 – Intersection Segments



A large part of the quality control was done automatically with computer algorithms and queries. Technicians carried a tape recorder on their travel time runs, and used them to note problem areas if encountered. While stopped, a driver would record the run number, the type of incident or problem, and the time it occurred down to the second. Examples of incidents or events that technicians would record are: construction, accidents, school zones, trains, overflowing left-turn queues, school bus stops, emergency vehicles, and signal preemption. The comments collected by the drivers are shown in **Figure 25** and are differentiated by comment type. For example, those times when the drivers encountered an active school zone, that was noted for the applicable speed limit. If the observation was determined to be non-recurring, the data for the segment was flagged so that it was not included in the calculation of averages.

Figure 25 - Driver Comments



Driver Comments
Source: MAG 2003 Regional Travel Speed Study

Once the data had gone through the quality control process, it was uploaded to the project website so that team members and MAG staff could view the data. Data was transferred and reviewed weekly, so the website was also updated on a weekly basis. The information on the website included everything completed to date and could be viewed but not edited. Only the project manager could edit the data on the website. The data collection supervisor would review the information, and from that, prepare a schedule for technicians for the next week. This ensured that no runs were repeated unnecessarily. MAG staff could use the website to view the progress to date as well as data summaries including speeds and levels of service.

3.6 Data Analysis

The data analysis includes various levels of review, automated Quality Assurance/Quality Control (QA/QC), and manual QA/QC. Many of the primary steps taken to process the large amounts of data are shown below.

- Assign segments for aggregation purposes
  - intersection segment
  - speed limit
  - school zone speed (if applicable)
  - number of lanes
  - Area Type/Facility Type
  - Jurisdiction
- Calculate average Space Mean Speed and Time Mean Speed.
- Calculate the queue measure as the first point in the segment where the speed <= 3 MPH and extends to the first intersection.
- Calculate the stop delay as the count of one second GPS points where the speed <=3 MPH
- Calculate the segment delay as the difference between travel time and free flow travel time.
- Reference: LOS based on delay and speed parameters
- Calculate travel time
- Calculate free flow travel time
- Average by intersection segment

3.7 Data Aggregation

The summary data has been aggregated on various levels. Data can be viewed from levels as detailed as the raw 1-second point data to the intersection segments. This allows the data to be presented in various forms depending on the audience. **Figure 24** illustrates the segmentation of the data for the Intersection Segments.

3.8 Problems in Data Collection

In a project as large as this travel time study, data collection challenges are expected. Construction was an issue in several locations. Travel time runs could not be conducted on roadways that were under construction because the data would not be meaningful to the project. Technicians noted areas of construction during the mapping process. If construction was completed, travel time runs were conducted on those roadways as they became available. Otherwise, they are noted as being under construction and travel time runs were delayed if at all possible.

Another challenge was hiring, training, and maintaining enough technicians to expeditiously conduct the travel time runs. Although only eight drivers were required, not all technicians were available at all times. It was necessary to hire and train a pool of technicians to ensure coverage for any given day.

Other problems included accidents or other incidents that distorted the typical conditions and accidents involving test vehicles. Locations where accidents or incidents prevented collection of typical data were noted at driven at a later date during typical conditions.

At one point in the study, for a period of over a month, one satellite was out of service and caused the AM runs to be delayed until a different satellite was available.

3.9 Georeferenced Digital Video

This study used digital video for quality control and is referenced in GIS to review travel time runs. In the GIS system, a user can click on any point along a corridor and view the digital video from a travel time run, starting at that point. This enhancement provides benefits including: identification of problems, illustration at public meetings, and use in future projects.

4.0 2002 Speeds and Travel Times

There was an enormous amount of data collected for the 2002-2003 Travel Speed Study. The easiest way to present and assimilate the information is in tables, charts, and graphs. This section presents the results of the study in visual format, allowing the reader to reach individual judgments at their discretion, and proffering summary conclusions only, by section.

The following sections display the relationship between speeds and functional class for the 1,600 centerline miles of roadway included in the study. This section displays all information collected for this study for evaluation, interpretation, and use in developing and prioritizing future projects.

4.1 Travel Speeds by Jurisdiction

Table 4 summarizes the results by jurisdiction and facility type, while Table 5 tabulates the results for all facility types by jurisdiction. Tables 4 and 5 provide summaries of the travel time runs including:

- Functional class and jurisdiction
- Travel Speed – average speed for all routes
- Speed Limit – weighted average speed limits for each run performed, may vary by time period depending on the number of runs on various routes
- % Posted Speed Limit (CI) – represents the ratio of Travel Speed to Speed Limit
- Running Speed – Average speed for travel times > 3 mph
- Stop Delay – average amount of time spent < 3 mph per mile
- Segment Delay – Delay encountered over all segments less than the theoretical time to traverse the segments.
- Control Delay – Stop Delay times 1.3 (30% higher than stop delay)

Table 4 – Jurisdictional Breakdown

Jurisdiction	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
Apache Junction	-	9.3	-	-	15.1	24.4
Avondale	-	8.0	-	-	24.0	31.9
Buckeye	-	15.7	15.5	-	8.8	40.0
Carefree	-	-	-	-	3.0	3.0
Cave Creek	-	-	-	-	2.4	2.4
Chandler	1.6	9.0	10.1	-	217.4	238.0
El Mirage	-	-	-	-	17.2	17.2
Fountain Hills	-	-	8.0	-	-	8.0
Gila River	-	14.0	-	-	9.8	23.8
Gilbert	-	-	-	-	82.5	82.5
Glendale	-	17.1	10.0	23.4	173.1	223.6
Goodyear	-	14.0	16.2	-	21.9	52.1
Guadalupe	2.5	2.5	-	-	3.5	8.6
Litchfield Park	-	-	-	-	5.2	5.2
Maricopa County	-	-	-	-	39.3	39.3
Mesa	0.7	48.3	-	-	330.0	379.8
Paradise Valley	-	-	-	-	22.1	22.1
Peoria	-	13.3	-	9.1	70.6	93.1
Phoenix	69.0	178.5	2.5	24.3	1029.0	1304.1
Queen Creek	-	-	-	-	21.4	21.4
Salt River	-	19.3	21.9	-	18.4	60.3
Scottsdale	-	15.2	8.6	-	178.4	202.2
Surprise	-	-	14.3	-	28.7	43.0
Tempe	16.8	40.8	-	-	148.1	205.7
Tolleson	-	4.0	-	-	4.0	8.0
ALL	90.6	408.8	107.2	56.9	2473.9	3139.7

Table 5 – Travel Speed, CI, Running Speed, and Delay

Jurisdiction	Travel Speed (MPH)	Speed Limit (MPH)	% Posted Speed	Running Speed (MPH)	Stop Delay (seconds/mile)	Segment Delay (seconds/mile)	Control Delay (seconds/mile)
Apache Junction	47.6	49.6	95.9%	49.2	8.9	18.5	11.6
Avondale	49.2	52.9	92.9%	50.7	6.0	15.9	7.9
Buckeye	56.3	59.4	94.7%	56.5	1.1	7.6	2.8
Carefree	36.5	31.0	117.7%	36.9	1.2	1.6	1.6
Cave Creek	42.5	44.1	96.3%	45.7	12.5	18.4	16.2
Chandler	36.9	45.1	81.8%	39.7	15.2	31.8	19.9
El Mirage	38.6	42.6	90.5%	40.5	9.1	18.9	11.8
Fountain Hills	42.2	51.7	81.6%	44.8	11.5	26.7	15.0
Gila River	64.1	60.5	106.0%	64.3	0.4	1.4	1.1
Gilbert	36.4	44.8	81.2%	38.8	14.2	30.8	18.4
Glendale	39.4	44.0	89.6%	41.9	19.3	30.8	25.3
Goodyear	53.7	56.6	94.8%	54.5	4.4	11.8	6.5
Guadalupe	46.2	43.9	105.2%	47.1	10.7	32.9	18.1
Litchfield Park	43.5	43.5	100.0%	45.5	5.1	8.8	6.6
Maricopa County	33.3	37.8	88.1%	36.0	18.6	31.5	24.1
Mesa	40.8	46.8	87.3%	42.8	12.3	26.3	16.6
Paradise Valley	33.7	38.1	88.7%	36.1	13.9	25.4	18.1
Peoria	39.2	44.0	89.0%	41.9	22.8	37.0	29.7
Phoenix	40.3	44.7	90.2%	42.3	15.0	28.8	20.9
Queen Creek	39.0	42.7	91.4%	40.1	3.0	12.4	3.9
Salt River	50.4	58.0	87.0%	51.8	7.7	22.6	19.5
Scottsdale	38.8	46.2	84.0%	41.2	17.2	33.1	22.7
Surprise	42.2	47.0	89.7%	44.4	12.6	24.2	16.4
Tempe	41.0	47.8	85.7%	43.0	16.2	34.9	23.9
Tolleson	49.3	47.3	104.2%	50.5	7.8	22.6	17.4

Figures 26-39 summarize the data for each of the time periods. **Table 6** includes the summaries of the average speed by jurisdiction. **Tables 7-9** includes the results summarized by roadway functional classification and area type.

Figure 26 - Average Freeway Speed - AM

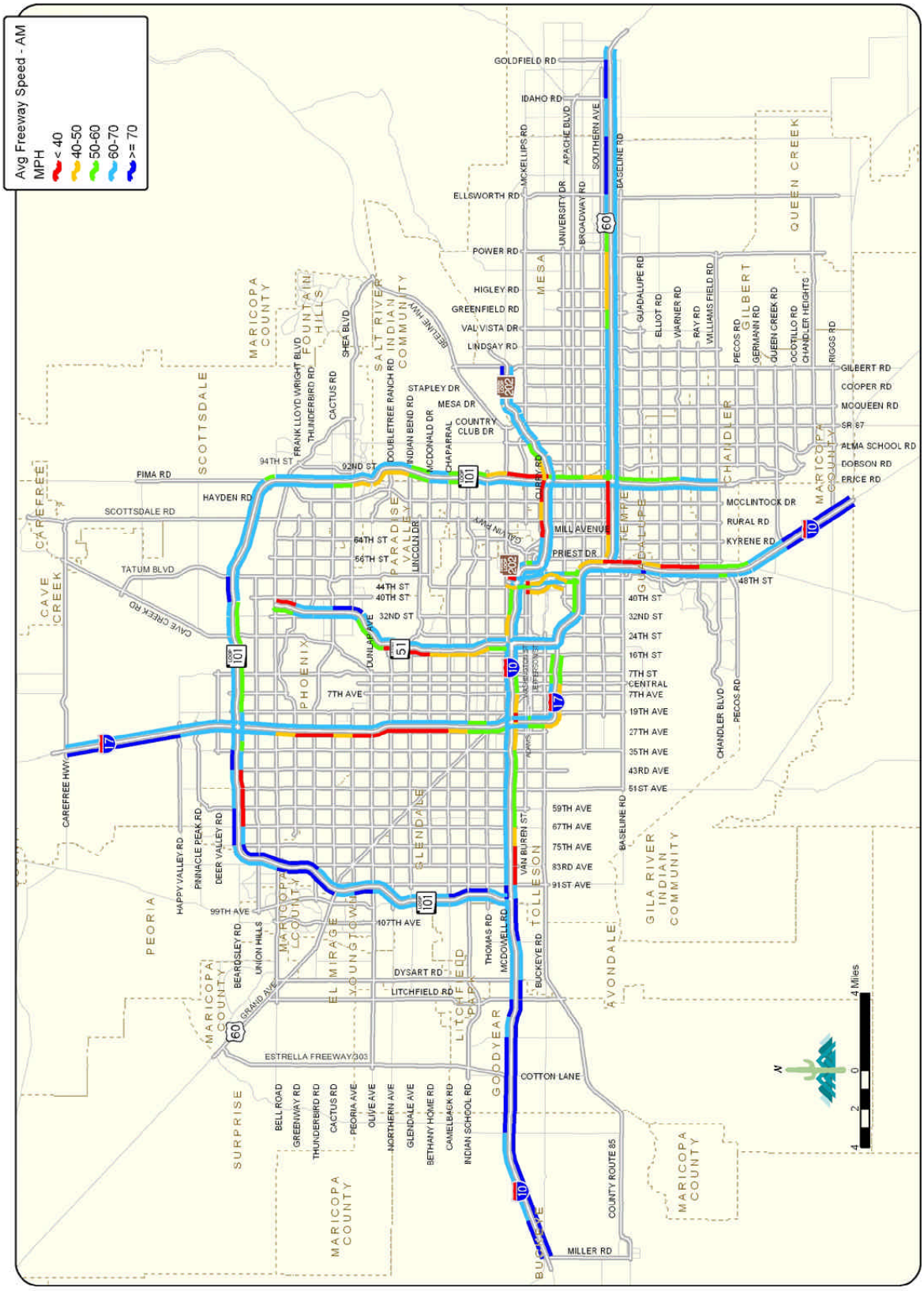


Figure 27 - Average Freeway Speed - Mid-Day

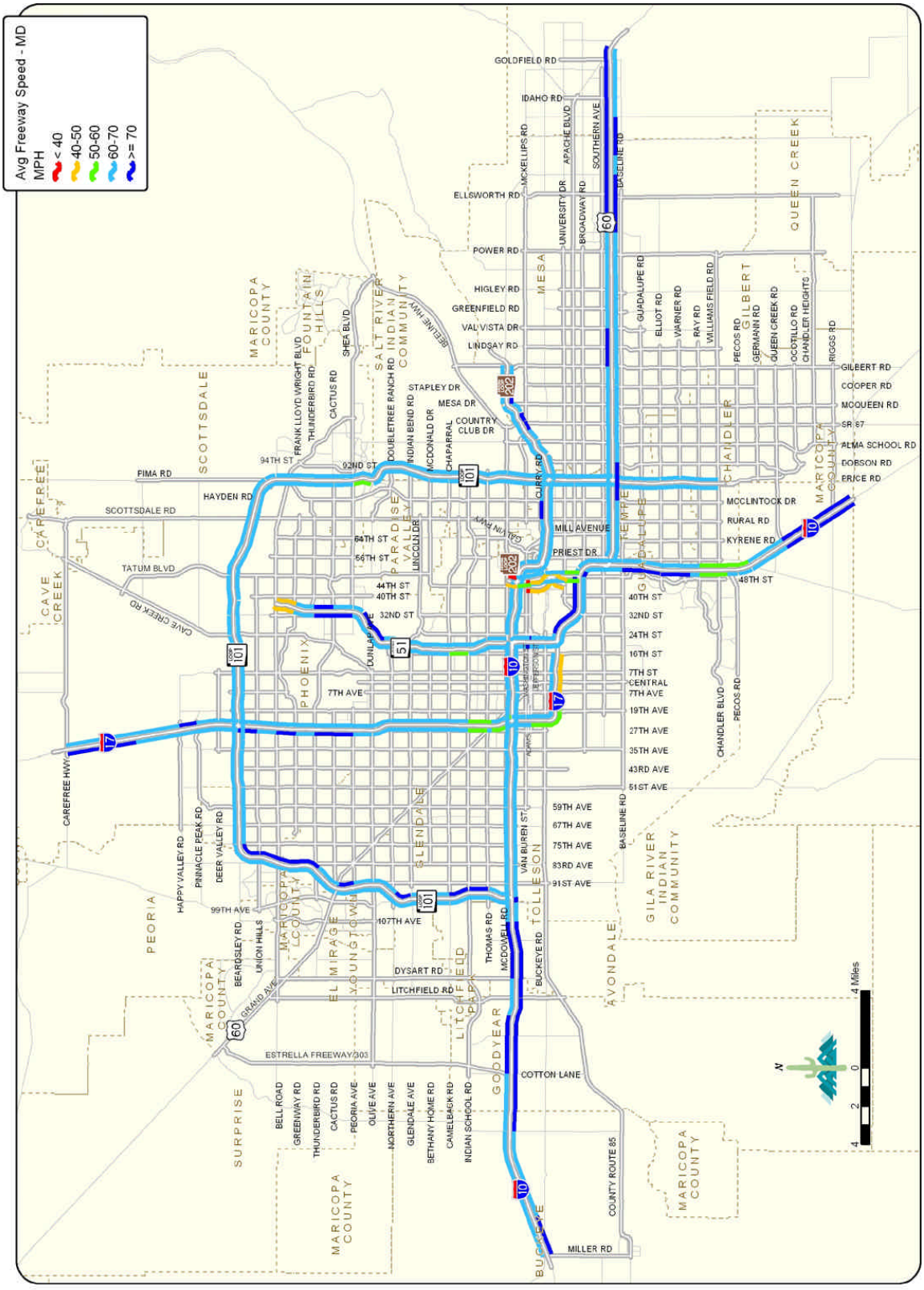


Figure 28 – Average Freeway Speed – PM

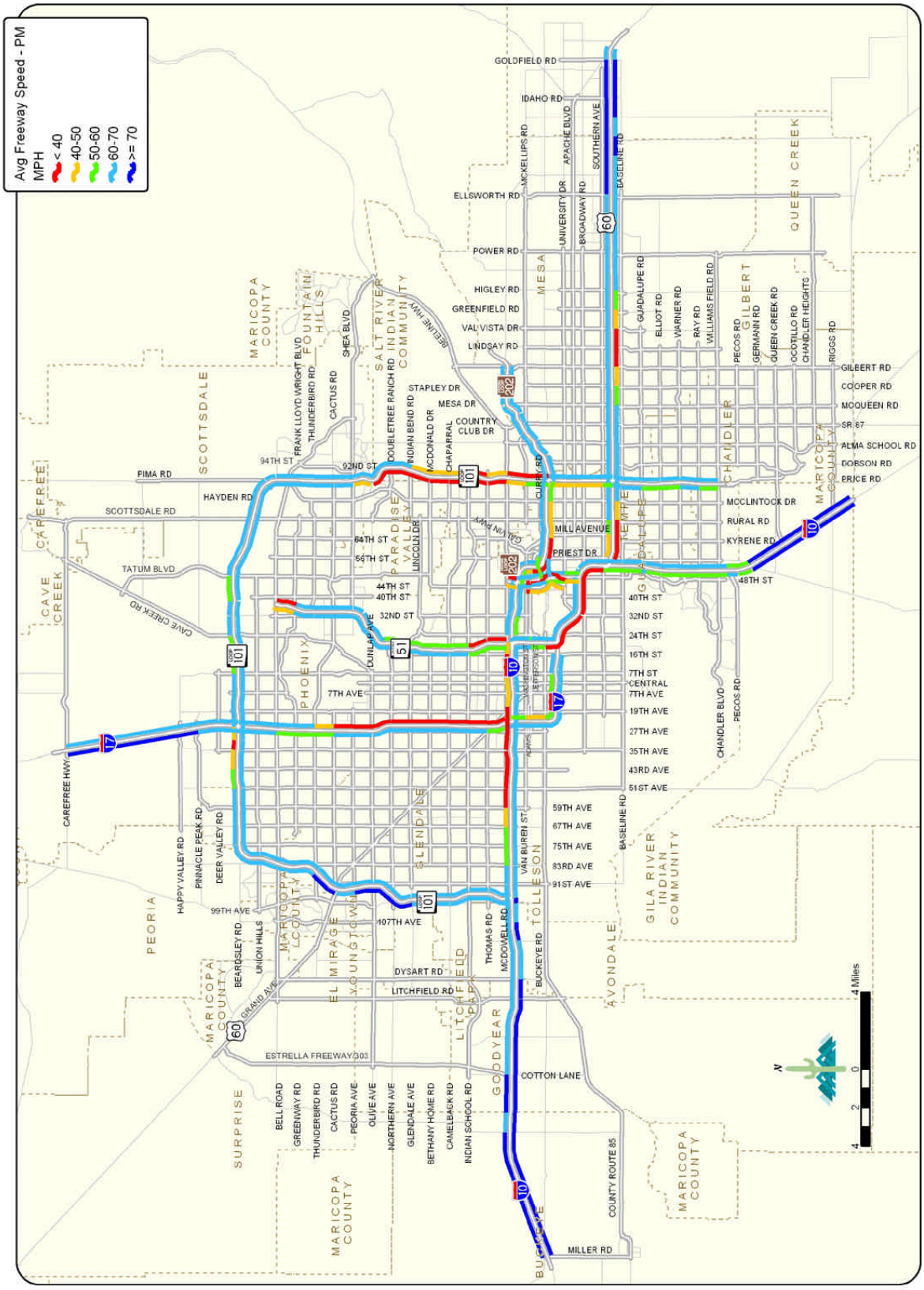


Figure 29 - Average HOV Speed - AM

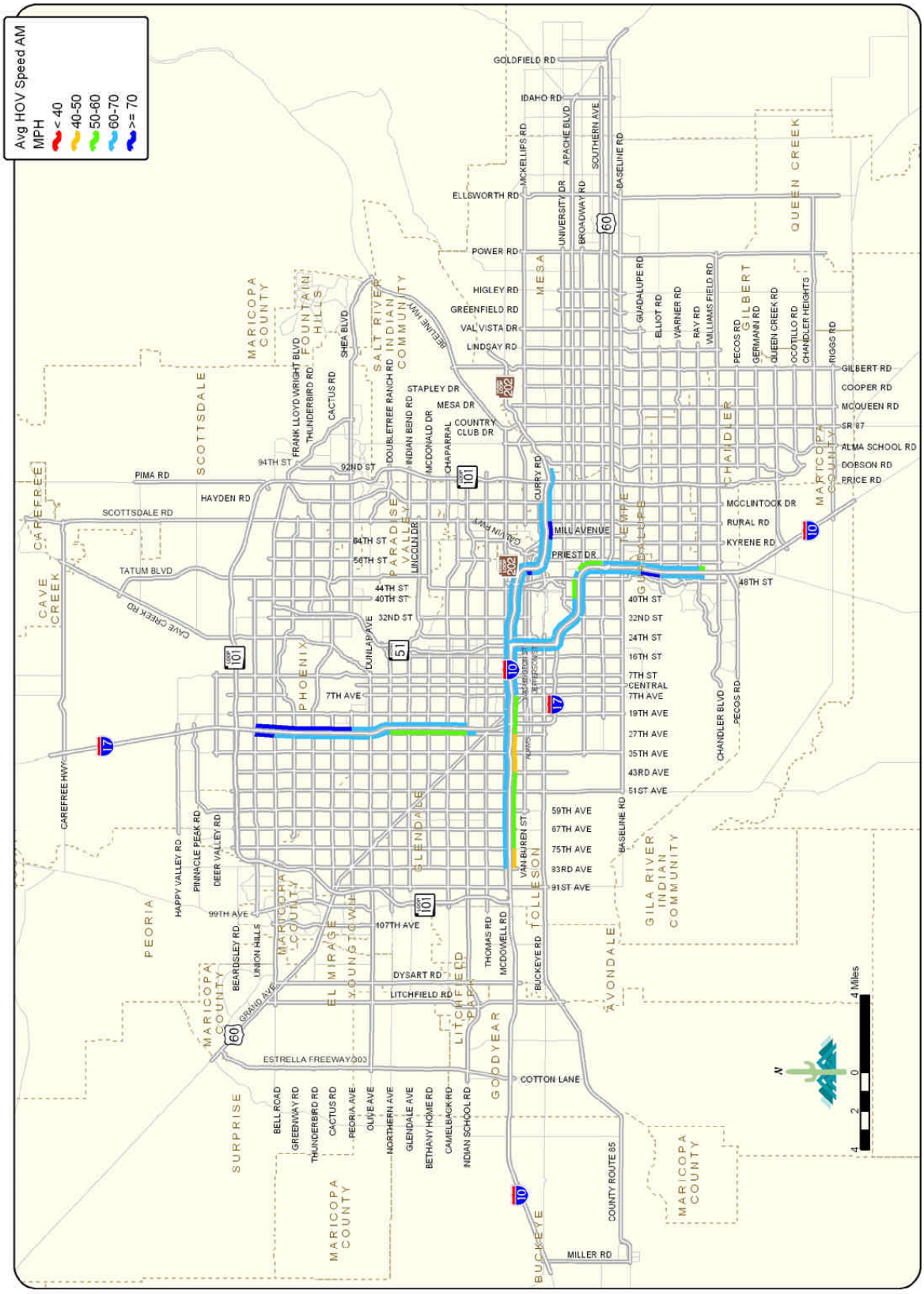


Figure 30 - Average HOV Speed - PM

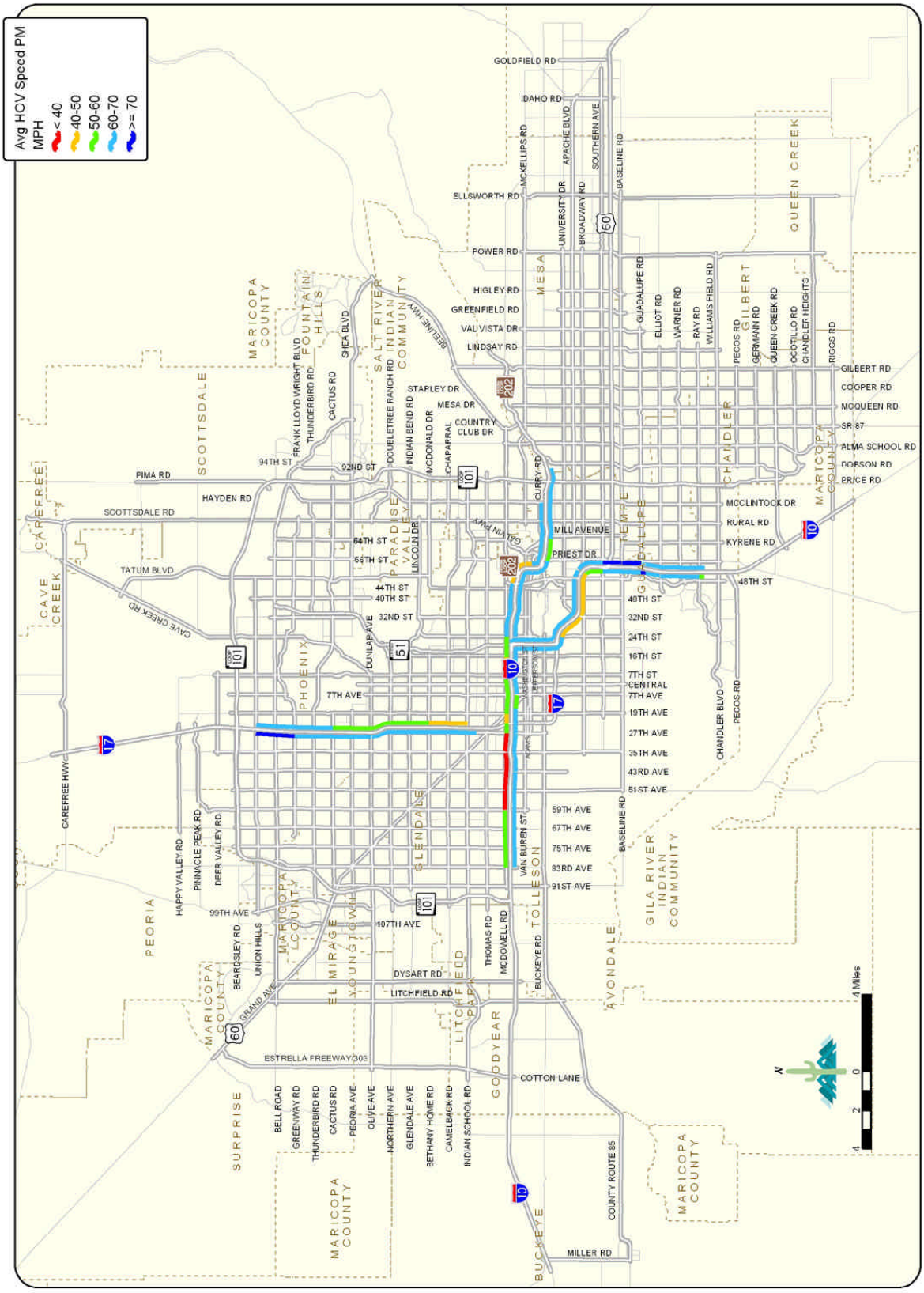


Figure 31 - Arterial Average Speed - AM

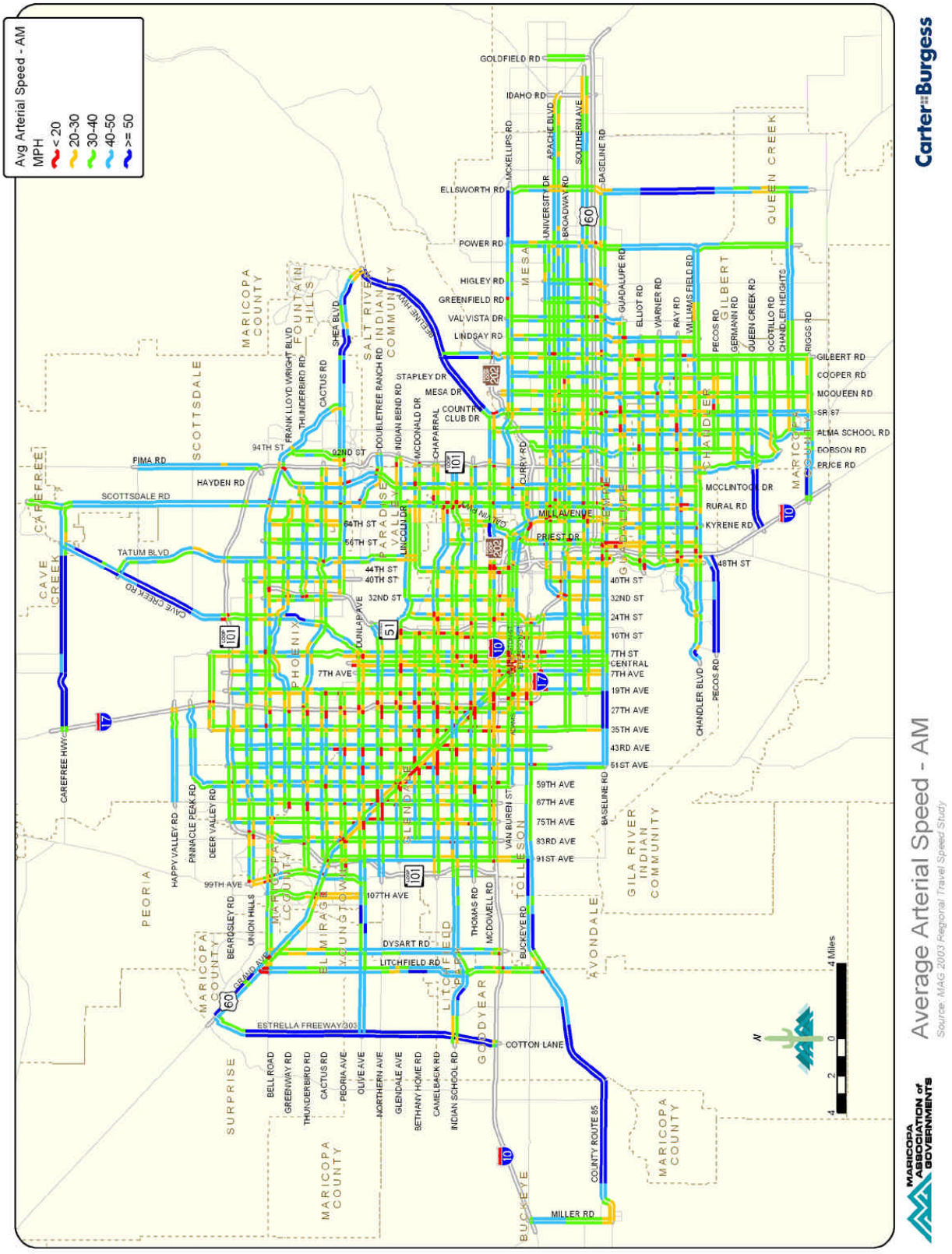


Figure 32 –Arterial Average Speed - Mid-Day

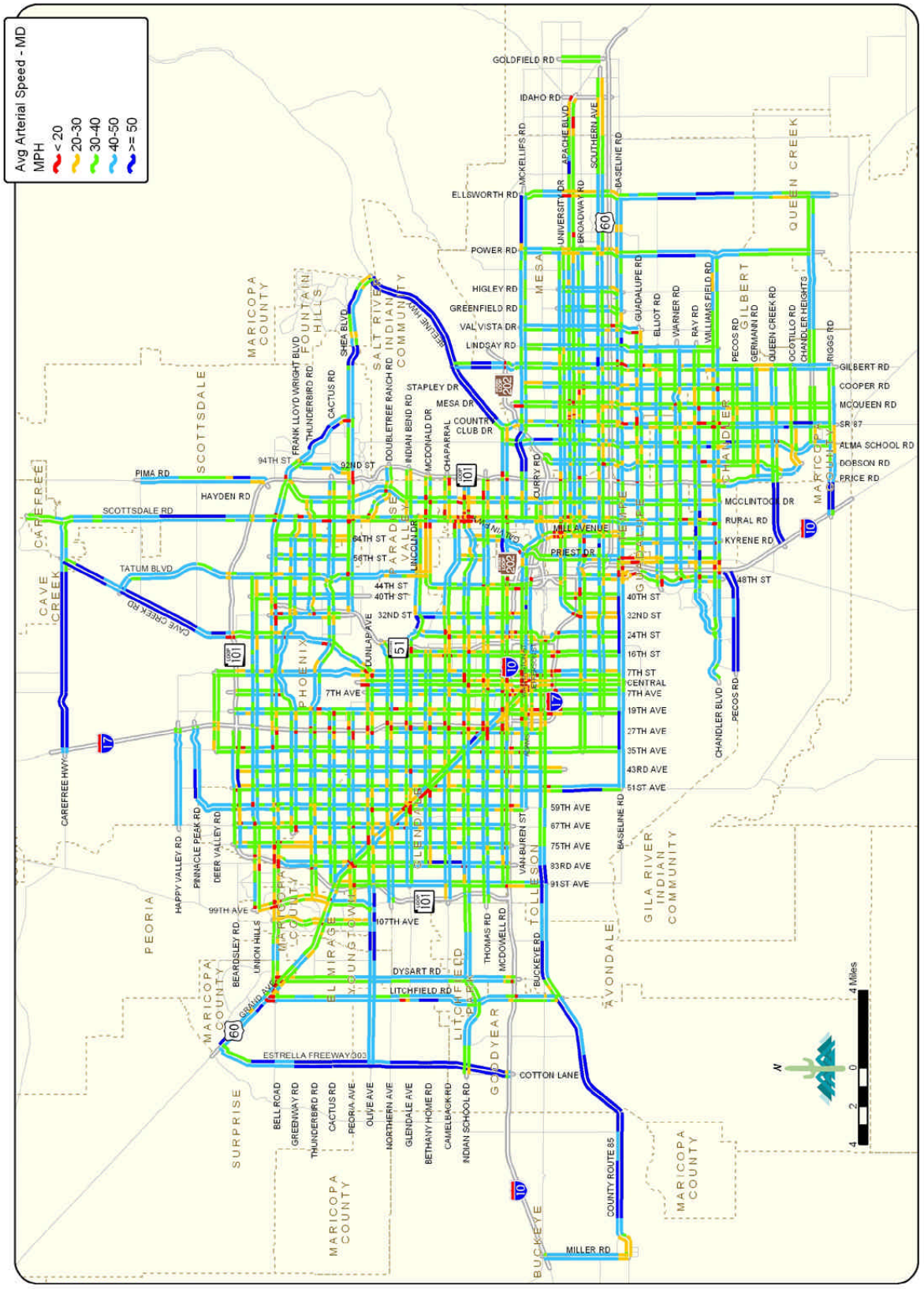


Figure 33 - Arterial Average Speed - PM

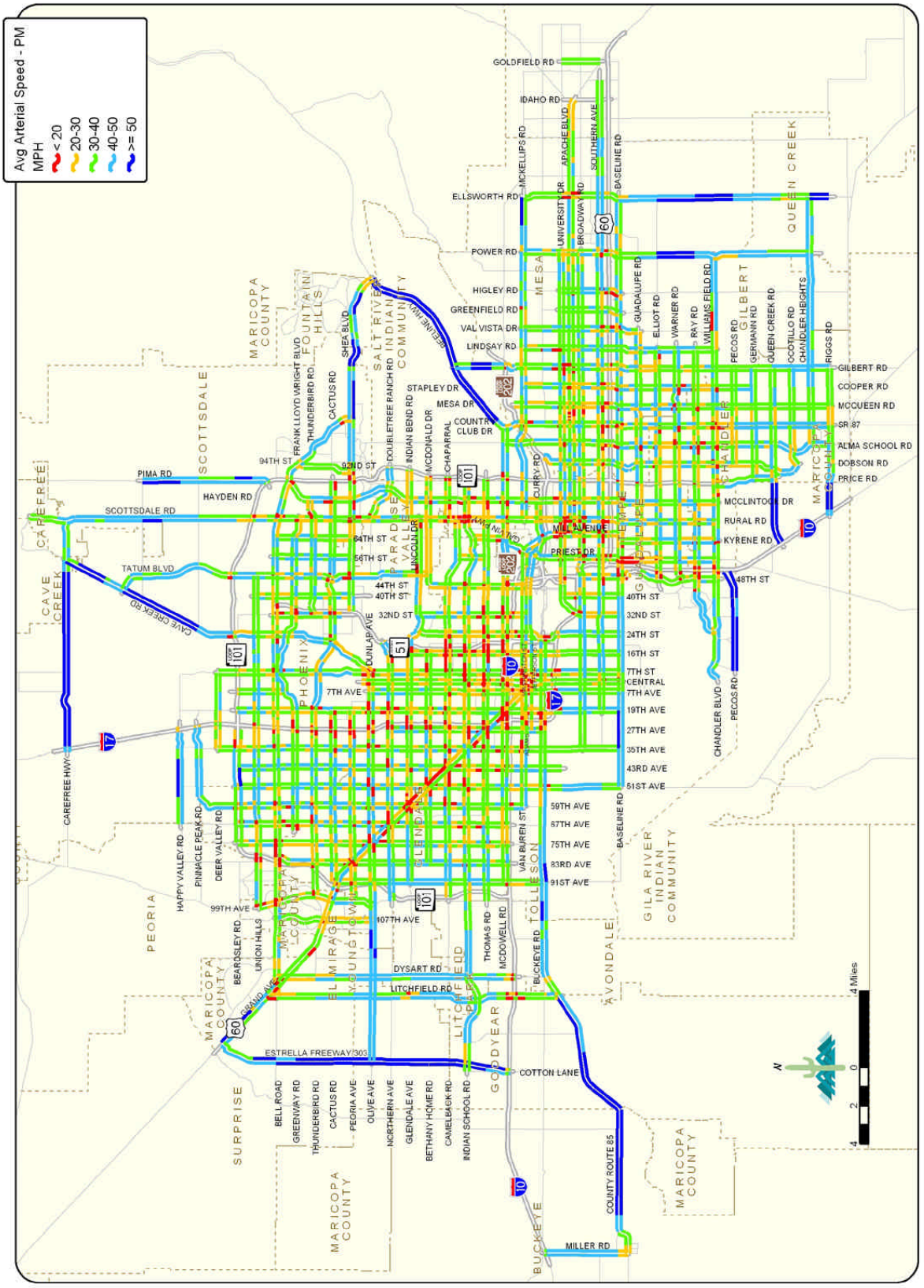


Figure 34- Freeway Percent of Posted Speed - AM

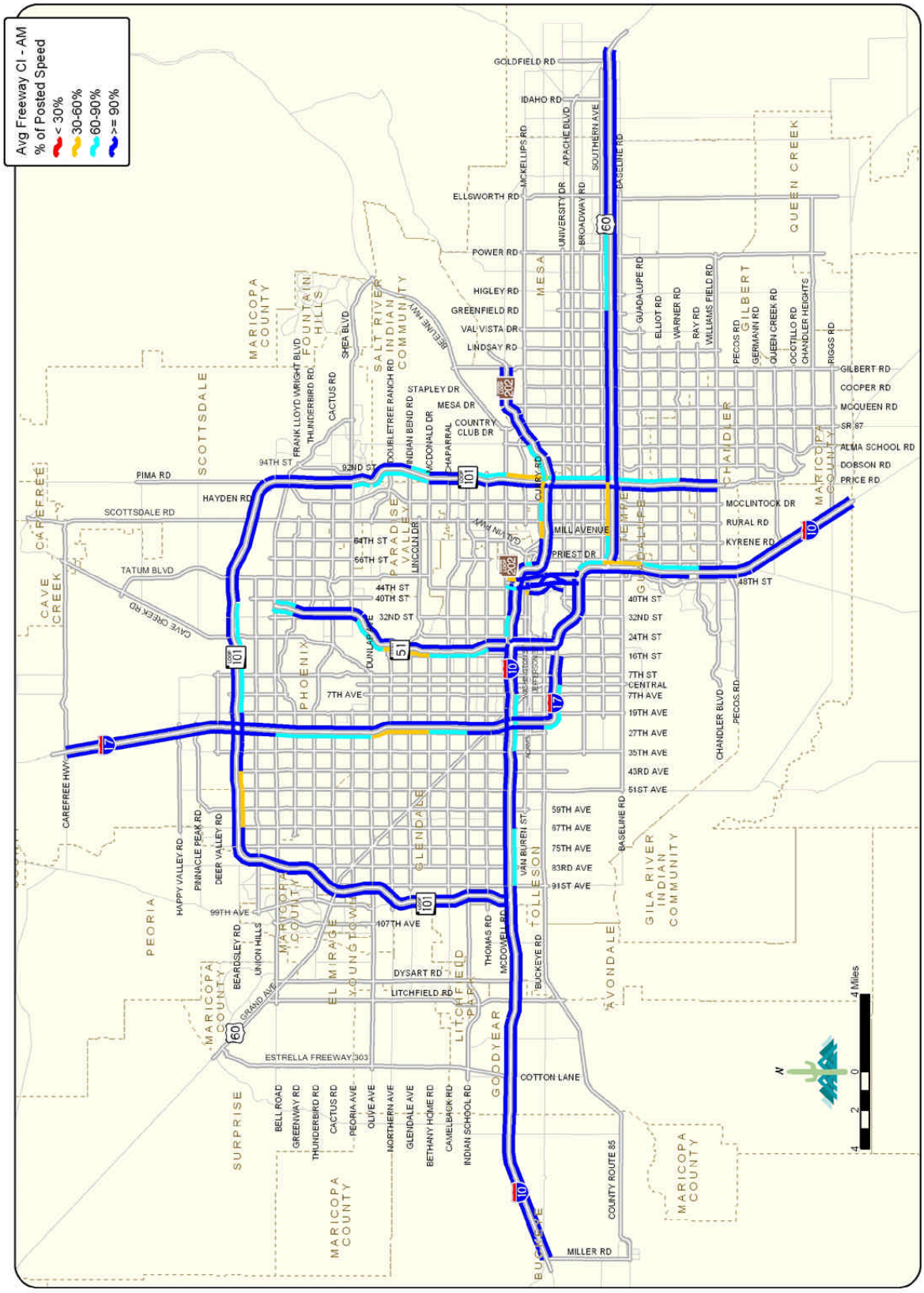


Figure 35 – Freeway Percent of Posted Speed – Mid-Day

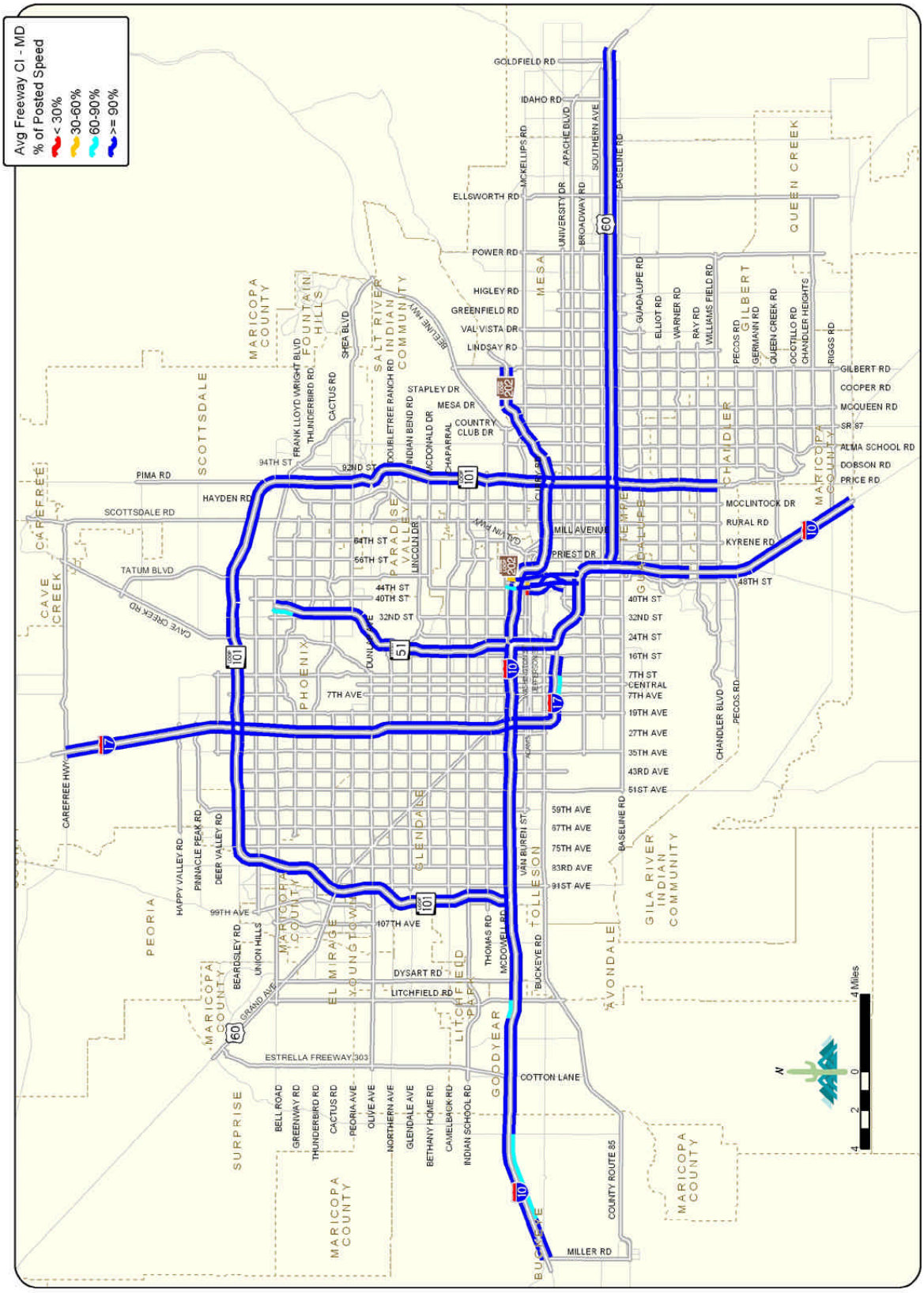


Figure 36 - Freeway Percent of Posted Speed - PM

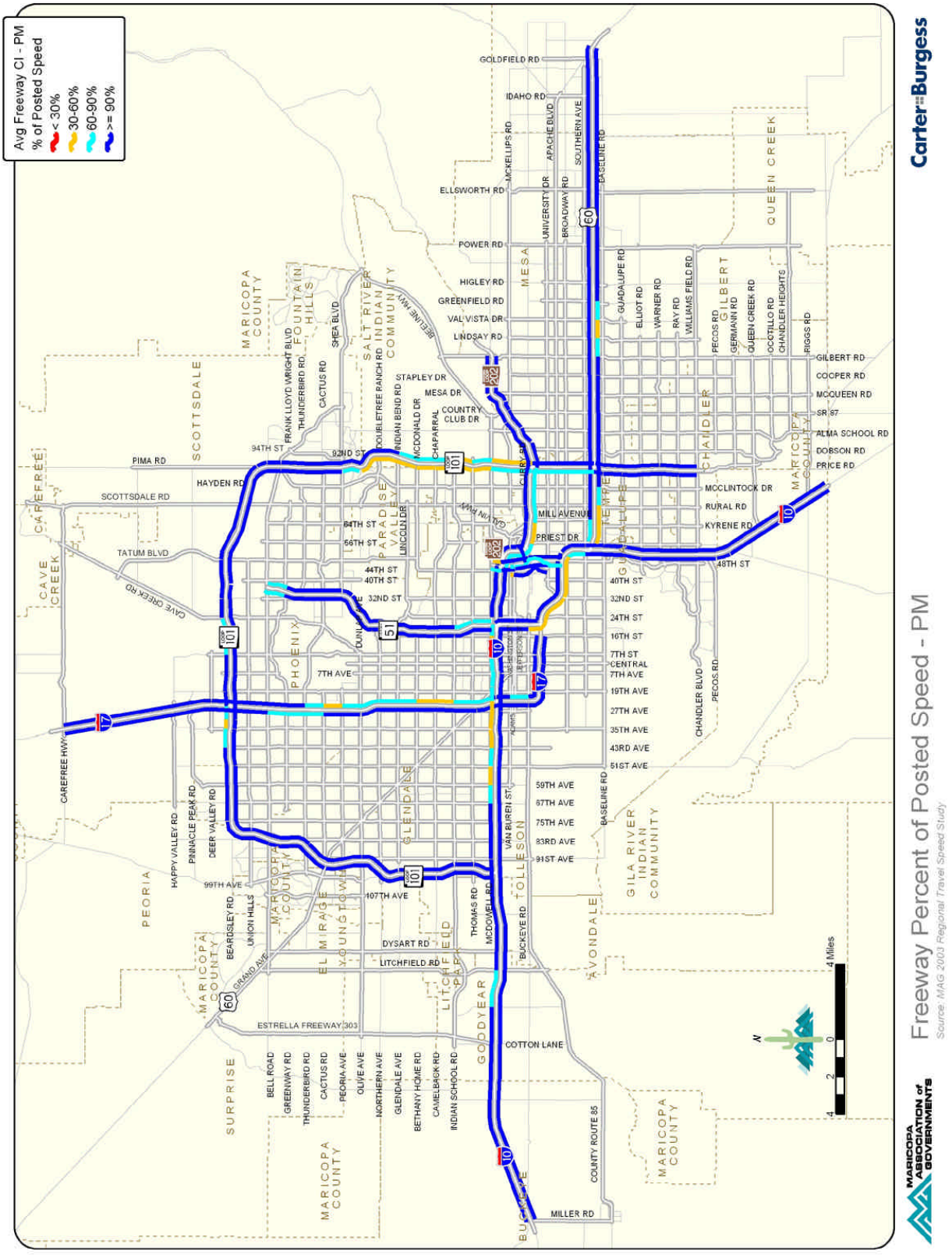


Figure 37 - Arterial Percent of Posted Speed - AM

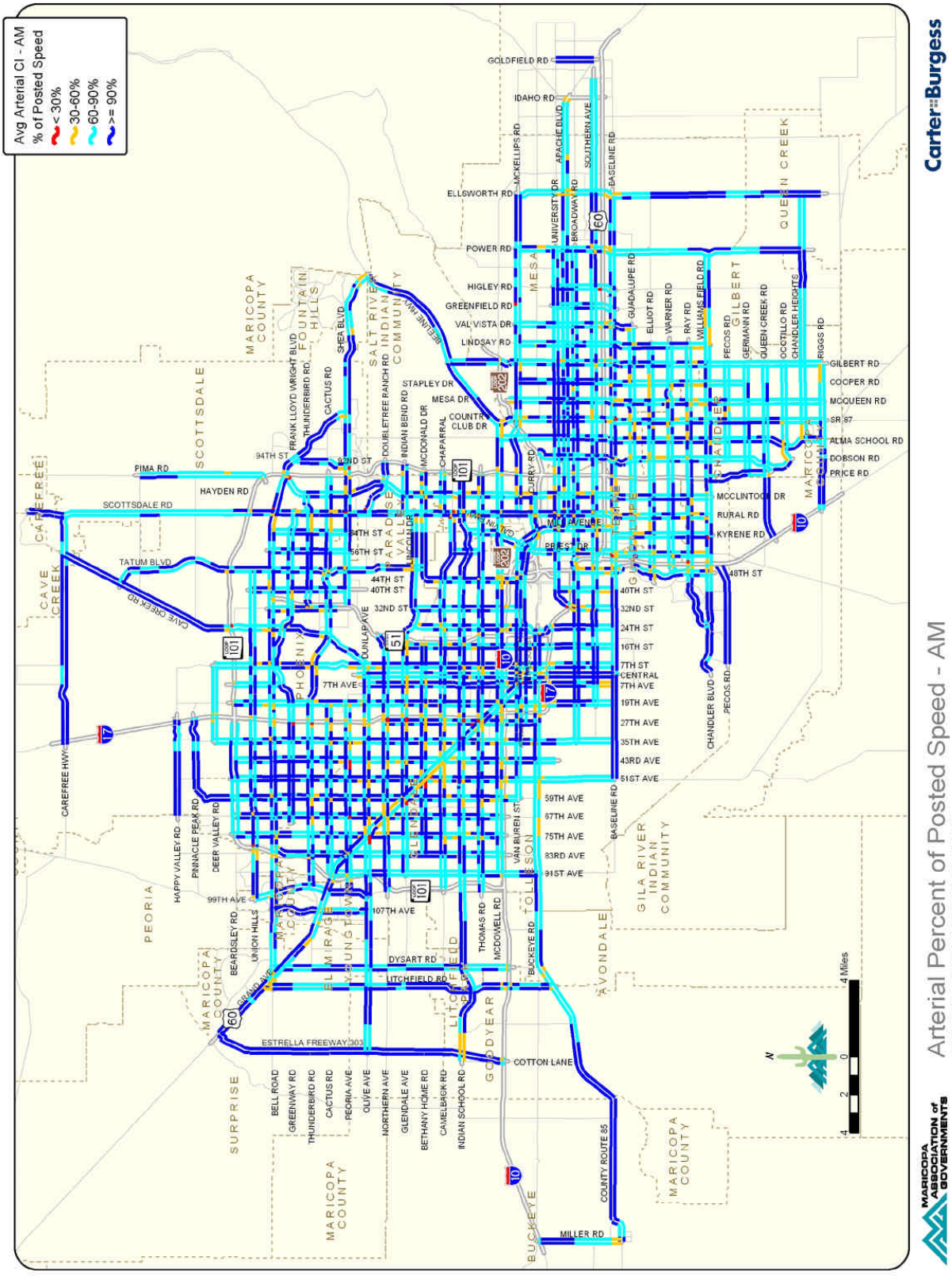


Figure 38 – Arterial Percent of Posted Speed – Mid-Day

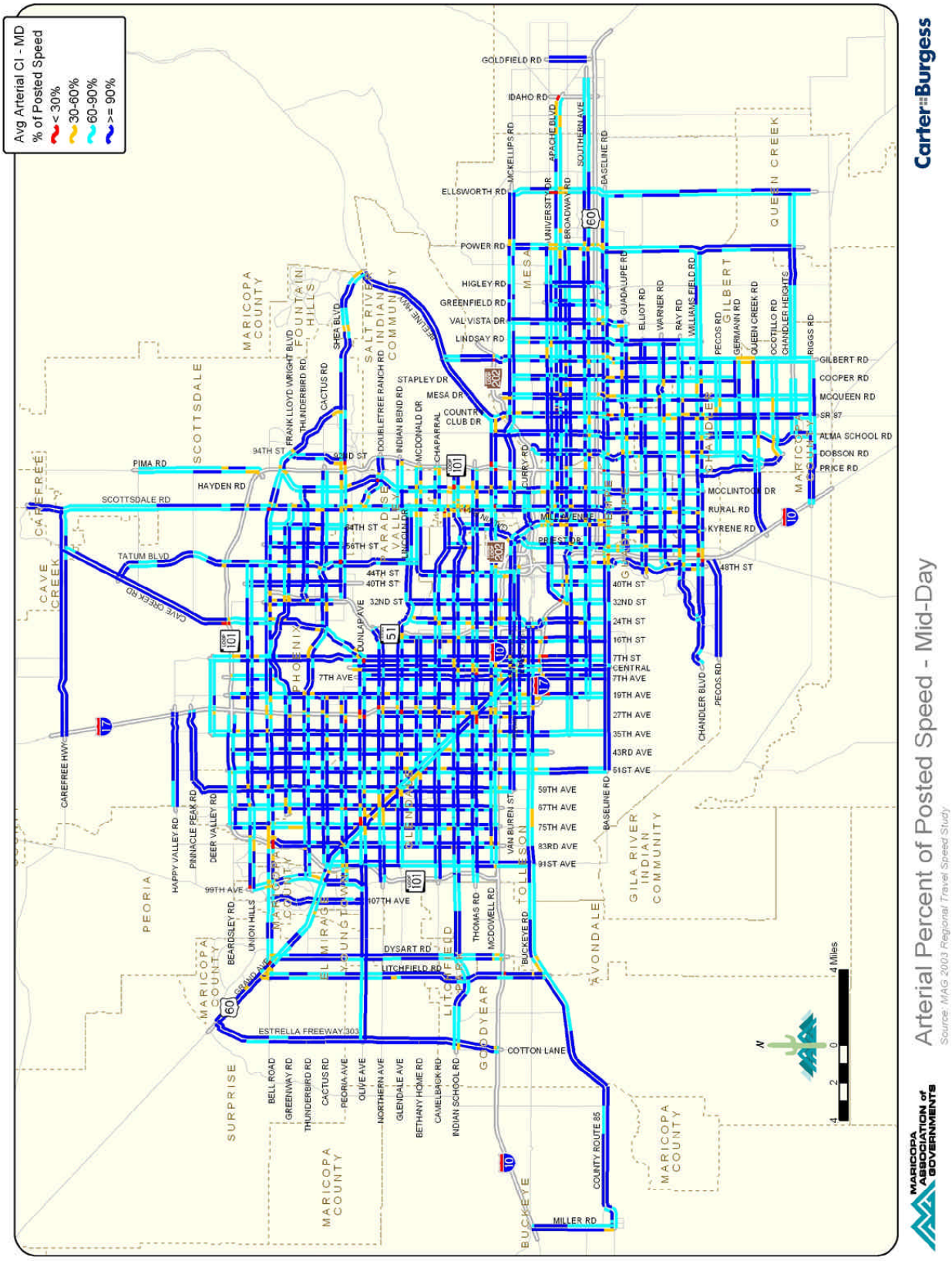


Figure 39 - Arterial Percent of Posted Speed - PM

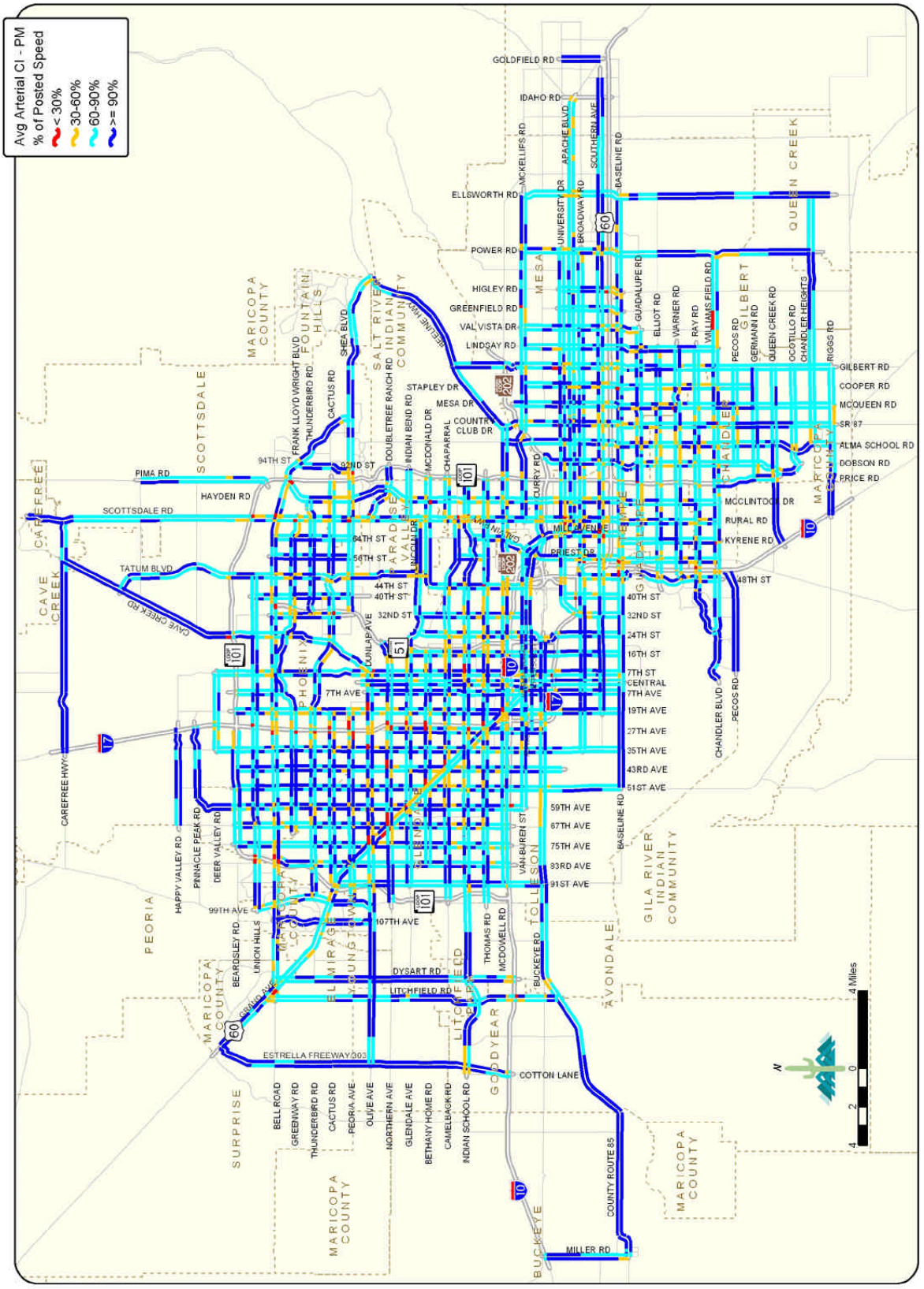


Table 6 – AM, MD and PM Weighted Average Speeds

	Arterial					Freeway				
				Change in Avg Speed					Change in Avg Speed	
Jurisdiction	AM	MD	PM	AM-MD	MD-PM	AM	MD	PM	AM-MD	MD-PM
Apache Junction	31.9	31.0	33.9	-0.9	2.9	69.4	71.5	70.4	2.1	-1.1
Avondale	42.0	41.4	40.7	-0.6	-0.7	69.6	70.5	68.2	0.9	-2.2
Buckeye	45.4	46.2	46.9	0.8	0.7	71.4	68.9	72.1	-2.5	3.2
Carefree	37.1	37.0	35.6	-0.2	-1.3	0.0	0.0	0.0	0.0	0.0
Cave Creek	43.8	42.2	41.5	-1.6	-0.7	0.0	0.0	0.0	0.0	0.0
Chandler	35.8	37.6	35.2	1.8	-2.4	59.1	63.0	60.0	3.9	-3.1
El Mirage	38.4	39.9	38.3	1.5	-1.6	0.0	0.0	0.0	0.0	0.0
Fountain Hills	42.9	42.2	41.6	-0.7	-0.6	0.0	0.0	0.0	0.0	0.0
Gila River	54.3	57.3	55.3	3.1	-2.0	70.1	69.6	70.8	-0.5	1.1
Gilbert	36.4	37.8	36.0	1.5	-1.8	0.0	0.0	0.0	0.0	0.0
Glendale	37.5	38.8	36.2	1.3	-2.5	65.7	68.0	66.8	2.3	-1.2
Goodyear	46.7	48.6	45.8	1.9	-2.8	72.1	71.2	70.9	-0.9	-0.3
Guadalupe	21.7	22.7	18.9	0.9	-3.8	59.0	69.3	66.0	10.3	-3.3
Litchfield Park	44.5	41.5	43.1	-3.0	1.6	0.0	0.0	0.0	0.0	0.0
Maricopa County	34.1	32.5	32.9	-1.6	0.4	0.0	0.0	0.0	0.0	0.0
Mesa	37.8	39.4	35.9	1.6	-3.5	64.0	68.7	64.5	4.8	-4.2
Paradise Valley	34.0	34.8	33.1	0.8	-1.7	0.0	0.0	0.0	0.0	0.0
Peoria	34.3	34.9	32.3	0.6	-2.6	70.1	69.3	69.1	-0.8	-0.1
Phoenix	35.7	38.0	34.7	2.3	-3.3	60.5	66.0	57.9	5.6	-8.1
Queen Creek	37.7	38.4	40.6	0.7	2.2	0.0	0.0	0.0	0.0	0.0
Salt River	49.0	54.9	50.5	5.9	-4.4	54.9	63.5	40.0	8.6	-23.5
Scottsdale	38.0	37.7	35.2	-0.3	-2.5	62.0	63.1	63.6	1.1	0.5
Surprise	43.6	41.7	40.9	-1.9	-0.7	0.0	0.0	0.0	0.0	0.0
Tempe	34.1	36.8	32.1	2.6	-4.6	58.1	68.0	58.8	9.9	-9.2
Tolleson	30.3	33.3	30.6	3.0	-2.7	59.0	67.5	66.3	8.5	-1.2
All	36.8	38.6	35.6	1.8	-3.0	61.9	67.0	60.5	5.1	-6.4

Table 7 – AM Weighted Average Speed by ATFT and Lanes

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	62.3	58.6	-	28.6	30.9	36.8
CBD (Outlying)	All	63.9	57.0	36.8	28.4	34.2	38.6
Mixed Urban	All	67.2	59.5	-	-	35.8	39.1
Suburban	All	56.6	66.8	47.0	30.7	38.8	42.9
Rural	1	-	-	55.6	-	39.5	42.6
	2 or more	-	66.5	53.7	-	42.5	51.0
ALL		64.5	61.4	51.7	28.9	36.4	40.7

Table 8 – Midday Weighted Average Speed by ATFT and Lanes

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	-	64.6	-	29.9	31.7	-
CBD (Outlying)	All	-	66.2	39.6	31.9	36.5	-
Mixed Urban	All	-	66.7	-	-	37.4	-
Suburban	All	-	68.8	49.0	32.6	39.8	-
Rural	1	-	-	54.0	-	40.8	-
	2 or more	-	67.9	56.9	-	43.6	-
ALL		-	67.0	52.9	31.8	38.0	-

Table 9 – PM Weighted Average Speed by ATFT and Lanes

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	57.8	49.2	-	23.6	28.0	32.3
CBD (Outlying)	All	60.5	54.6	35.7	26.1	32.2	36.1
Mixed Urban	All	63.7	60.8	-	-	34.1	37.6
Suburban	All	61.7	67.0	47.2	31.1	38.4	42.8
Rural	1	-	-	56.4	-	40.8	43.7
	2 or more	-	62.9	55.2	-	42.3	50.4
ALL		61.0	60.4	52.2	26.8	35.1	39.4

4.2 Running Speeds by Area Type and Facility Type

Running speed is defined as the segment length divided by the segment travel time minus the stopped time (time less than 3 mph). **Tables 10-12** includes the running speed results summarized by roadway functional classification and area type.

Table 10 – AM Weighted Average Running Speed by ATFT and Lanes AM

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	62.3	58.6	-	33.9	33.2	38.7
CBD (Outlying)	All	63.9	57.2	38.9	34.7	36.4	40.5
Mixed Urban	All	67.2	59.8	-	-	38.3	41.2
Suburban	All	56.7	66.9	49.1	37.2	41.1	44.9
Rural	1	-	-	56.0	-	41.0	43.9
	2 or more	-	66.5	54.5	-	44.7	52.4
ALL		64.5	61.5	52.8	35.1	38.7	42.7

Table 11 – MD Weighted Average Running Speed by ATFT and Lanes AM

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	-	64.6	-	34.9	33.8	41.0
CBD (Outlying)	All	-	66.3	41.6	36.7	38.1	44.2
Mixed Urban	All	-	66.7	-	-	39.5	43.3
Suburban	All	-	68.8	50.2	39.7	41.9	46.0
Rural	1	-	-	54.4	-	41.9	44.6
	2 or more	-	67.9	57.3	-	45.6	54.4
ALL		-	67.0	53.6	37.1	40.0	45.0

Table 12 – PM Weighted Average Running Speed by ATFT and Lanes AM

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	57.8	49.5	-	30.3	30.8	34.8
CBD (Outlying)	All	60.6	54.9	38.2	32.9	34.8	38.5
Mixed Urban	All	63.7	60.9	-	-	37.1	40.2
Suburban	All	61.7	67.0	48.9	37.9	40.9	45.0
Rural	1	-	-	56.8	-	42.3	45.0
	2 or more	-	63.0	55.8	-	44.6	51.9
ALL		61.1	60.6	53.1	33.6	37.8	41.7

4.3 Speed Limits (Free Flow Speed) by Area Type and Functional Class

For the purpose of calculating delay, the weighted speed limit of a segment is considered the unconstrained travel speed. **Table 13** summarizes the average posted speed limit for each respective roadway functional class by area type and number of lanes. The speed limits and corresponding travel times are used to calculate delay and congestion index. The average speeds shown are weighted by the length of each segment including those instances when the speed changes mid-block.

Table 13 – Average Speed Limits (Free Flow Speed)

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	55.0	55.0	-	37.1	34.3	39.1
CBD (Outlying)	All	57.4	57.5	40.4	40.7	40.5	44.2
Mixed Urban	All	57.4	61.0	-	-	42.3	44.7
Suburban	All	55.0	64.2	53.5	42.5	44.8	47.8
Rural	1	-	-	54.9	-	47.1	48.6
	2 or more	-	70.4	57.1	-	47.7	56.3
ALL		57.0	61.8	53.6	40.6	42.7	46.2

4.4 Stop Delay

Stop Delay is one element that is no longer recognized by the *Highway Capacity Manual*, Transportation Research Board, 2000. But, for comparison purposes, it was calculated and defined as the point that the vehicle speed is reduced to 3 mph. The resulting average stop delay (seconds per mile) is shown in **Tables 14-16** according to Area Type/Facility Type

Table 14 – Stop Delay (Seconds per Mile) - AM

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	-	0.1	-	61.2	22.9	19.5
CBD (Outlying)	0.01	1.29	45.81	73.01	19.03	17.9
Mixed Urban	-	1.0	-	-	16.0	13.8
Suburban	0.8	0.6	6.7	61.0	10.6	9.9
Rural	-	0.2	1.2	-	8.0	5.8
ALL	0.0	0.8	4.1	69.5	14.9	13.4

Table 15 – Stop Delay (Seconds per Mile) - Midday

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	-	-	-	46.3	18.8	15.8
CBD (Outlying)	-	0.3	17.0	42.5	12.4	11.1
Mixed Urban	-	0.2	-	-	12.1	10.5
Suburban	-	-	3.9	42.9	9.3	8.2
Rural	-	-	1.2	-	6.1	4.2
ALL	-	0.2	2.4	43.0	11.1	9.5

Table 16 – Stop Delay (Seconds per Mile) - PM

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	0.2	2.0	-	129.7	34.7	32.4
CBD (Outlying)	0.6	1.5	24.0	86.4	26.3	24.2
Mixed Urban	0.3	0.6	-	-	21.7	18.9
Suburban	-	0.0	5.6	79.4	12.9	11.7
Rural	-	0.8	1.1	-	8.2	5.9
ALL	0.5	0.8	3.4	89.7	20.0	17.8

Tables 17-19 present the delay (seconds per mile) as calculated by segment. Values validated in research in the past by members of the team, determined that control delay was 30% larger than stop delay. This indicates that the delay encountered as drivers decelerate and then once again accelerating from a stop comprise of 30% more delay than represented by those times when stopped. Values shown for the freeway segments represent the delay when compared to the posted speed limit. This is done different than the arterials since there are many times when speeds do not drop below the 3 mph threshold on the freeways where stop delay would begin accruing.

Table 17 –Delay (Seconds per Mile) – AM

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	1.8	6.2	-	79.6	29.7	26.4
CBD (Outlying)	1.87	12.63	59.55	94.91	24.74	24.9
Mixed Urban	0.3	11.2	-	-	20.7	19.2
Suburban	15.9	5.2	8.7	79.3	13.8	13.5
Rural	-	6.0	1.6	-	10.4	8.5
ALL	1.8	9.3	5.4	90.3	19.4	18.6

Table 18 –Delay (Seconds per Mile) – Midday

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	-	0.2	-	60.2	24.4	20.5
CBD (Outlying)	-	0.66	22.14	55.23	16.08	14.4
Mixed Urban	-	1.1	-	-	15.8	13.7
Suburban	-	0.4	5.0	55.7	12.1	10.7
Rural	-	2.9	1.5	-	7.9	5.9
ALL	-	1.1	3.1	55.9	14.4	12.4

Table 19 –Delay (Seconds per Mile) - PM

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	4.9	24.0	-	168.6	45.2	45.4
CBD (Outlying)	6.02	16.97	31.20	112.38	34.20	33.8
Mixed Urban	5.8	7.4	-	-	28.2	25.4
Suburban	0.2	1.9	7.3	103.3	16.8	15.5
Rural	-	15.3	1.5	-	10.7	10.3
ALL	5.7	10.8	4.4	116.6	26.0	24.5

4.5 Congestion Index

Tables 20-22 include the summary data for congestion index by area type/facility type. In contrast to past efforts that summarized results solely on speed, using the mapping effort and subsequent linear reference system that was developed, the Congestion Index (% of posted speed) was calculated to represent the delay encountered.

Table 20 – Congestion Index – AM (% Posted Speed)

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	113.3%	106.5%	-	77.1%	90.5%	95.8%
CBD (Outlying)	111.5%	99.5%	91.2%	69.9%	84.4%	88.8%
Mixed Urban	117.4%	97.6%	-	-	84.7%	87.6%
Suburban	102.9%	104.1%	90.7%	72.5%	86.6%	89.9%
Rural	-	94.8%	99.6%	-	86.3%	90.2%
ALL	113.0%	99.3%	96.5%	71.1%	85.4%	88.8%

Table 21 – Congestion Index – Midday (% Posted Speed)

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	-	117.5%	-	80.8%	93.0%	100.5%
CBD (Outlying)	-	115.3%	98.0%	78.4%	90.1%	96.8%
Mixed Urban	-	110.3%	-	-	88.7%	92.7%
Suburban	-	107.5%	91.5%	76.8%	89.1%	92.4%
Rural	-	96.8%	98.9%	-	89.0%	92.7%
ALL	-	109.4%	96.5%	78.3%	89.3%	93.9%

Table 22 – Congestion Index – PM (% Posted Speed)

Area Type	Functional Classification					
	HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	105.1%	89.4%	-	63.7%	81.7%	84.9%
CBD (Outlying)	105.6%	95.2%	88.5%	64.1%	79.5%	83.7%
Mixed Urban	110.8%	99.8%	-	-	80.7%	84.5%
Suburban	112.2%	104.3%	90.6%	73.1%	85.8%	89.5%
Rural	-	89.3%	101.1%	-	87.9%	90.3%
ALL	107.0%	97.3%	97.1%	65.9%	82.5%	86.0%

4.6 Travel Time Between Cities

The travel time between the central business districts for 9 communities and the Sky Harbor Airport were computed. The 2002-2003 travel time study was comprehensive in nature and represents the speeds on all arterials and freeways within the MAG region. Therefore, this data joined with the extensive GIS network and linear reference system allows various elements to be calculated. This is a lengthy computer process and for example purposes, **Figures 40-42** are included to demonstrate the format of the travel time contours, additional figures are included in the appendix for various cities. **Tables 23 and 24** includes the travel times for the AM and PM Periods from/to each respective city centroid.

Table 23 – AM Place-to-Place Travel Time Matrix

	Destination							
Origin	Phoenix	Tempe	Scottsdale	Glendale	Peoria	Gilbert	Chandler	Mesa
Phoenix	-	16.8	19.8	18.9	24.1	27.0	27.7	21.5
Tempe	15.5	-	14.4	27.9	33.1	18.8	19.5	13.6
Scottsdale	19.7	14.9	-	31.7	36.9	22.0	22.6	16.7
Glendale	24.1	33.9	36.8	-	9.5	44.8	45.6	40.1
Peoria	30.4	40.2	43.2	10.4	-	51.1	51.8	46.4
Gilbert	32.1	20.0	25.8	44.2	49.3	-	10.9	12.9
Chandler	34.9	22.8	28.5	46.9	52.1	12.6	-	18.6
Mesa	24.4	11.1	15.7	36.4	41.6	12.1	15.4	-

Table 24 – PM Place-to-Place Travel Time Matrix

	Destination							
Origin	Phoenix	Tempe	Scottsdale	Glendale	Peoria	Gilbert	Chandler	Mesa
Phoenix	-	20.2	22.2	26.3	33.7	37.7	38.0	29.5
Tempe	15.4	-	17.8	36.9	43.5	23.7	24.1	16.7
Scottsdale	19.4	17.4	-	40.9	47.5	29.9	30.2	21.8
Glendale	20.5	31.5	33.5	-	10.6	48.9	49.3	40.7
Peoria	25.8	36.8	38.8	11.5	-	54.2	54.6	46.0
Gilbert	27.3	20.2	26.7	48.8	54.6	-	11.7	14.1
Chandler	29.1	21.9	28.4	50.5	56.4	13.8	-	19.8
Mesa	20.0	12.2	18.2	41.5	48.1	15.2	18.7	-

Figure 40 - Travel Time Contours - Phoenix Inbound AM

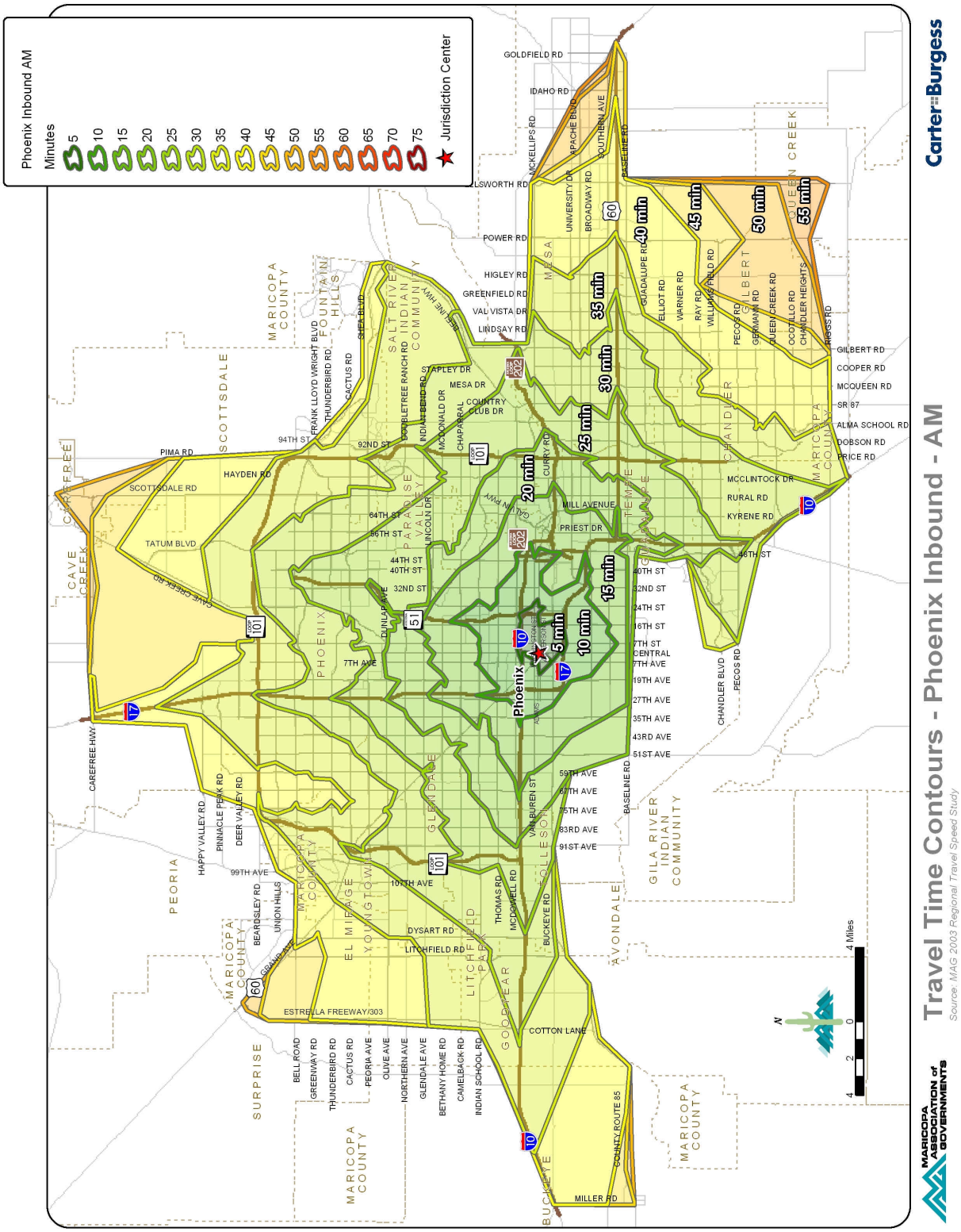


Figure 41 - Travel Time Contours - Phoenix Inbound Free Flow (Posted Speed Limit)

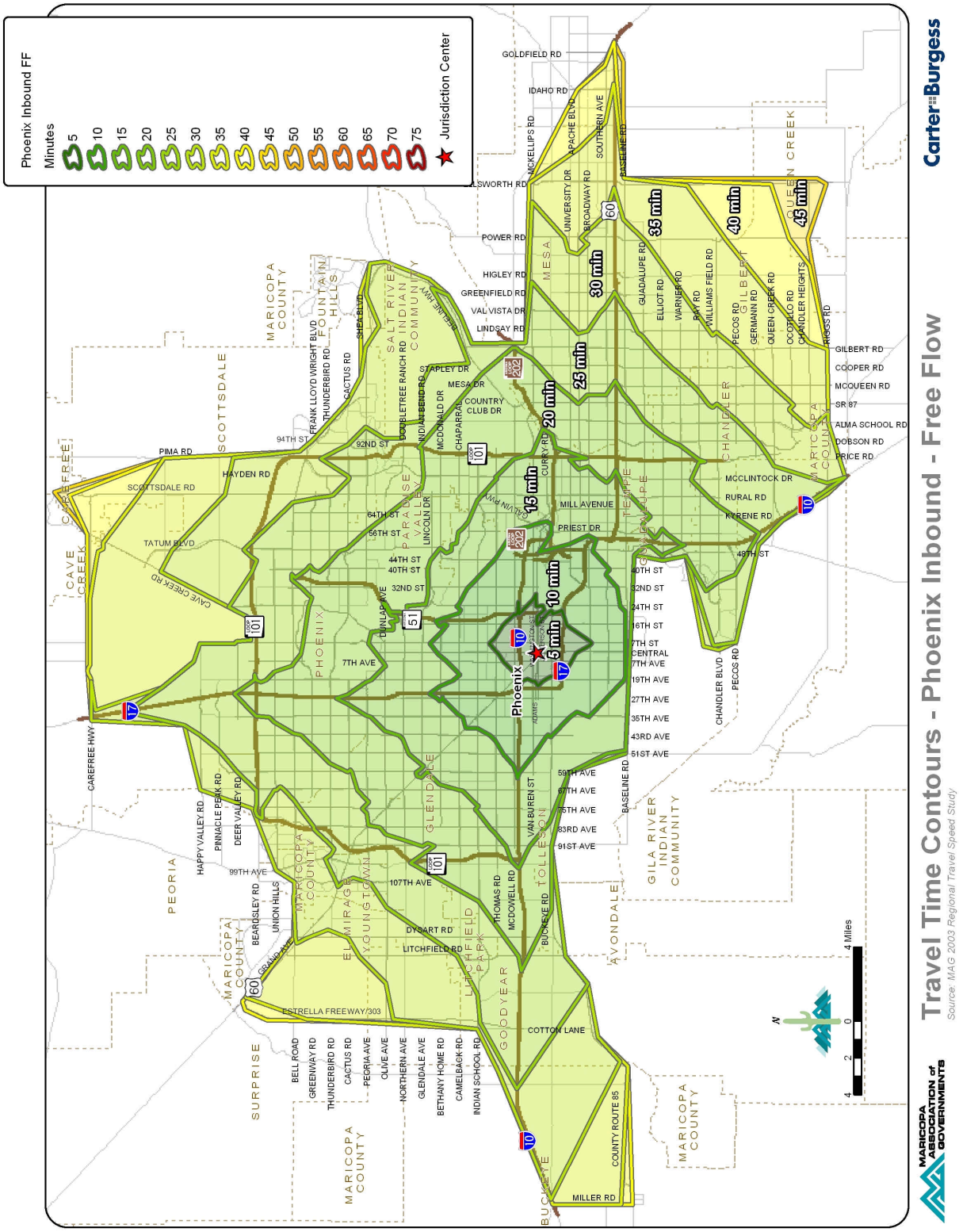
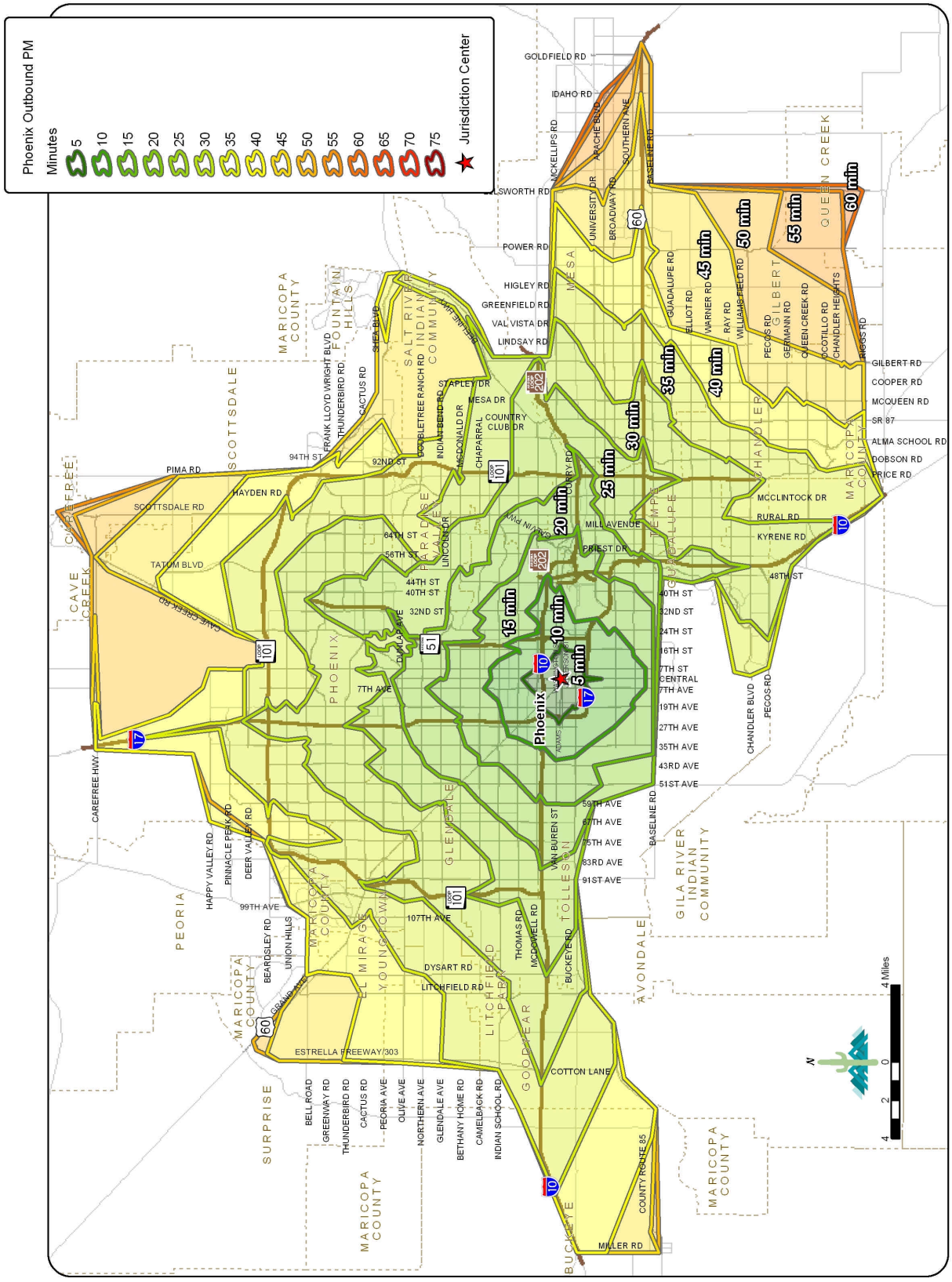


Figure 42 - Travel Time Contours - Phoenix Outbound PM



5.0 Traffic Delay at Intersections

5.1 Intersection Delay

Historically, three types of delay have been measured at signalized intersections: 1) stopped delay, 2) control delay, and 3) approach delay.

- Stopped delay is the duration that a vehicle is physically stopped waiting for the queue at the signalized intersection. **Figure 43** conceptually illustrates stopped delay as the flat part (t_2 to t_3) of the distance-time trajectory. Since vehicles must accelerate and decelerate some discretion must be exercised with regard to when a vehicle is considered stopped. For measuring purposes, a vehicle is considered stopped if the speed is below some threshold – say 3 mph. Although somewhat labor intensive, this measurement could historically be obtained quite easily with the use of a stopwatch. Consequently, it was used almost exclusively up until the late 1980's in most traffic engineering texts and the *Highway Capacity Manual*, Transportation Research Board, 2000.
- Control Delay is the total delay a vehicle experiences when progressing through a section of road influenced by a traffic signal. This includes the delay experienced while decelerating (t_1 to t_2), the time spent stopped (t_2 to t_3), and the delay experienced after the vehicle leaves the intersection, but has not accelerated to the free flow speed (t_3 to t_4). Furthermore, control delay is a better measurement because it reflects the entire delay caused by a traffic signal, not just the duration a vehicle is stopped. Consequently, the traffic engineering literatures and *Highway Capacity Manual*, Transportation Research Board, 2000 have used this measurement since the mid 1990's.
- Approach Delay is a subset of control delay and only includes the delay experienced while decelerating (t_1 to t_2) and the time spent stopped (t_2 to t_3). It excludes the delay experienced after the vehicle leaves the intersection, but has not accelerated to the free flow speed (t_3 to t_4).

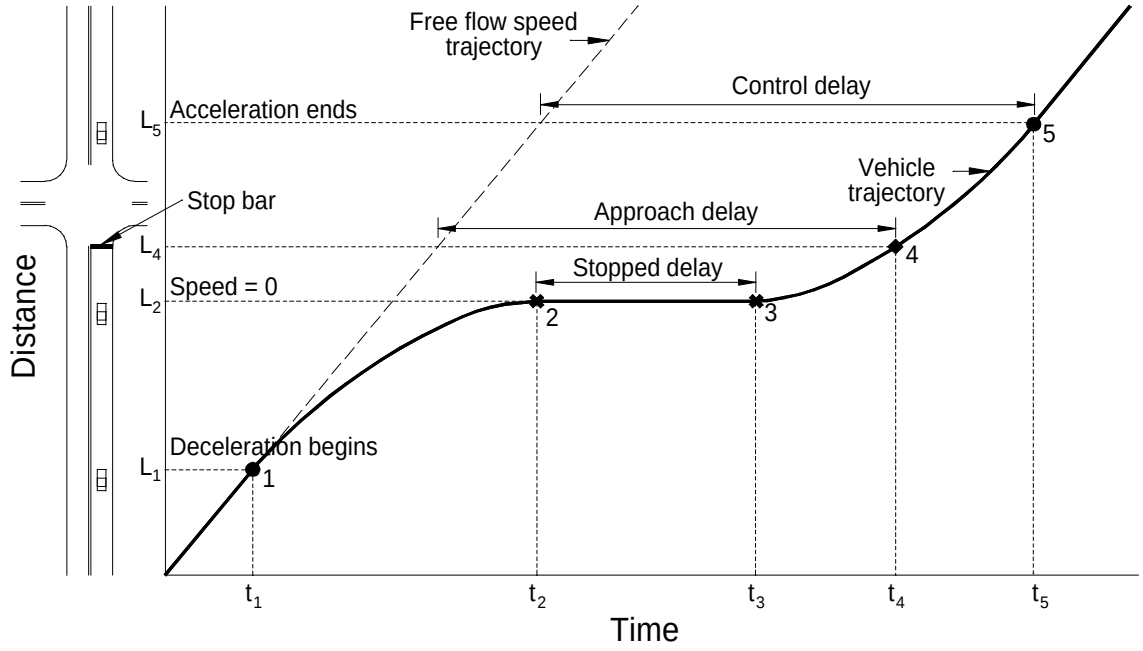


Figure 43 – Delay Measurements at Signalized Intersections

While this conversion from stopped delay to control delay was in process in the 1990s, traffic engineering professionals used the approximation that control delay was approximately 30% larger then stopped delay. A rather extensive study was undertaken at Louisiana State University (3) to verify that. In general the 30% was confirmed to be reasonable.

Figures 44-49 illustrate the delay for each segment on the arterials and freeways. They are shown separately since the delay methodology used is different for each of the basic functional classes. The delay on the arterials uses the control delay previously discussed Section 3.4. This includes determination of the stopped delay, and then inflating it by 30% to represent the overall control delay. For those segments on the freeway, the delay is representative of the number of seconds of delay when referenced to the theoretical travel time according to the posted speed limit on a per mile basis. Additional figures are included for reference for the PM period that provides more detail of various quadrants of the study region.

Figure 44 – Average Arterial Control Delay - AM

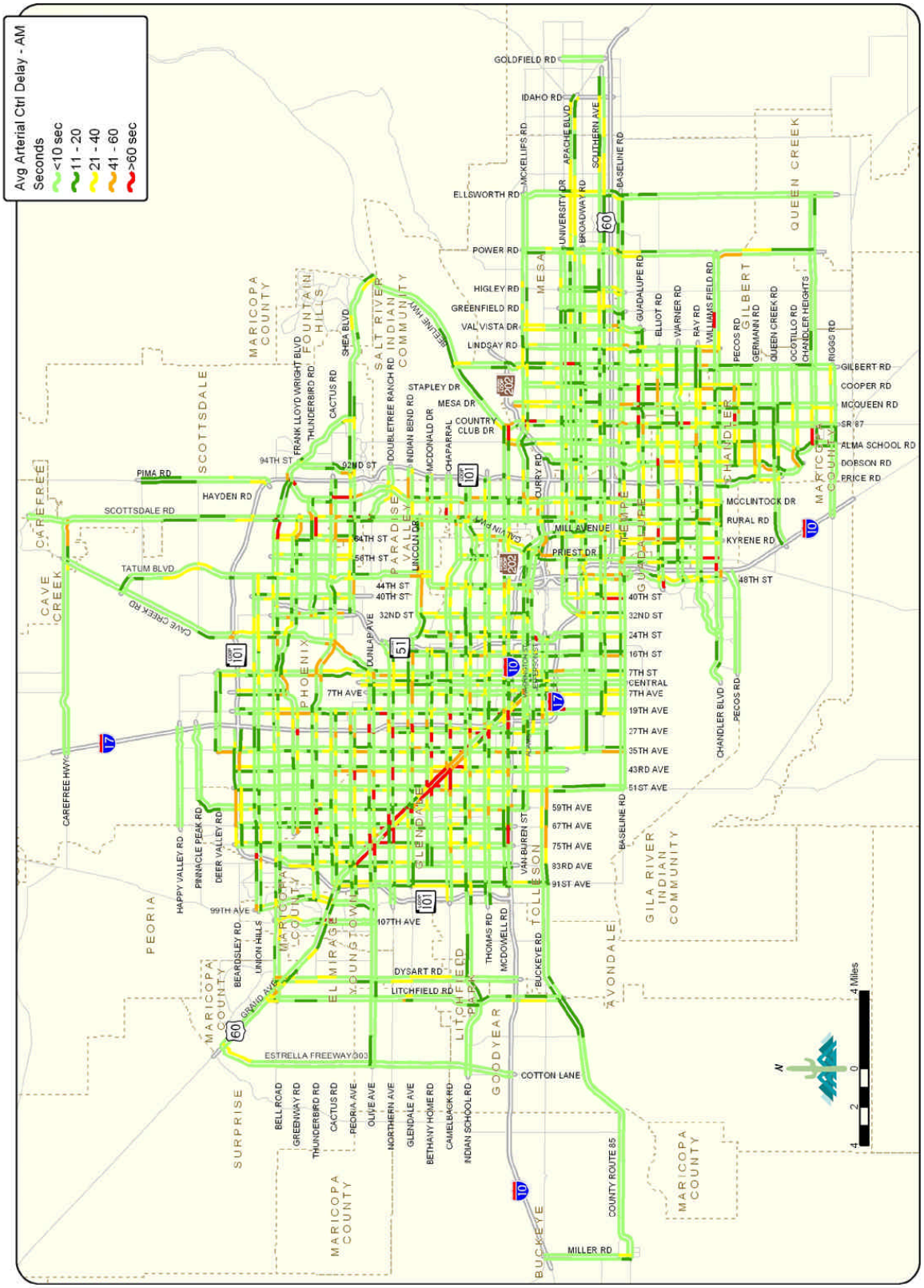


Figure 45 –Average Arterial Control Delay Mid-Day

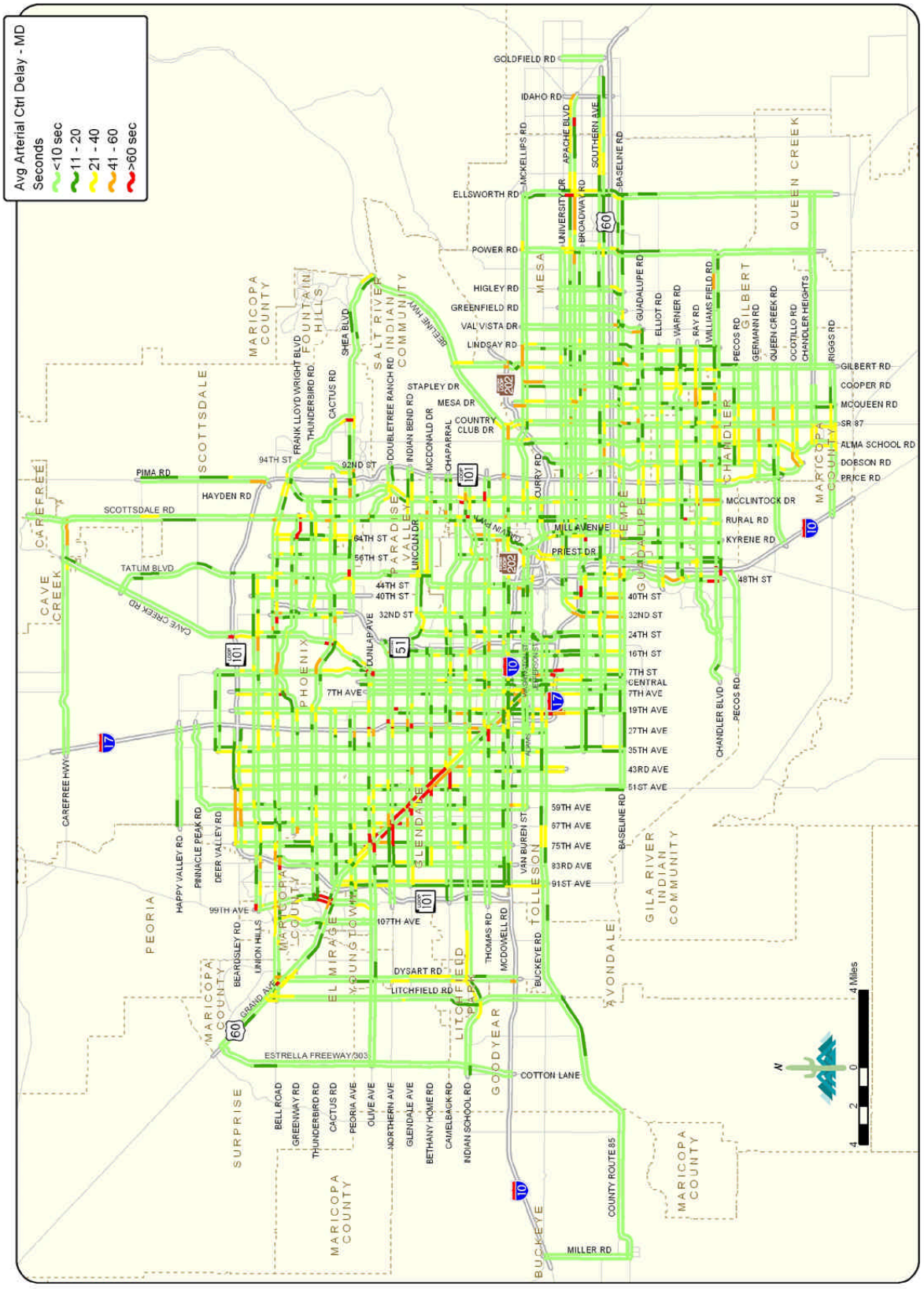


Figure 46 - Average Arterial Control Delay PM

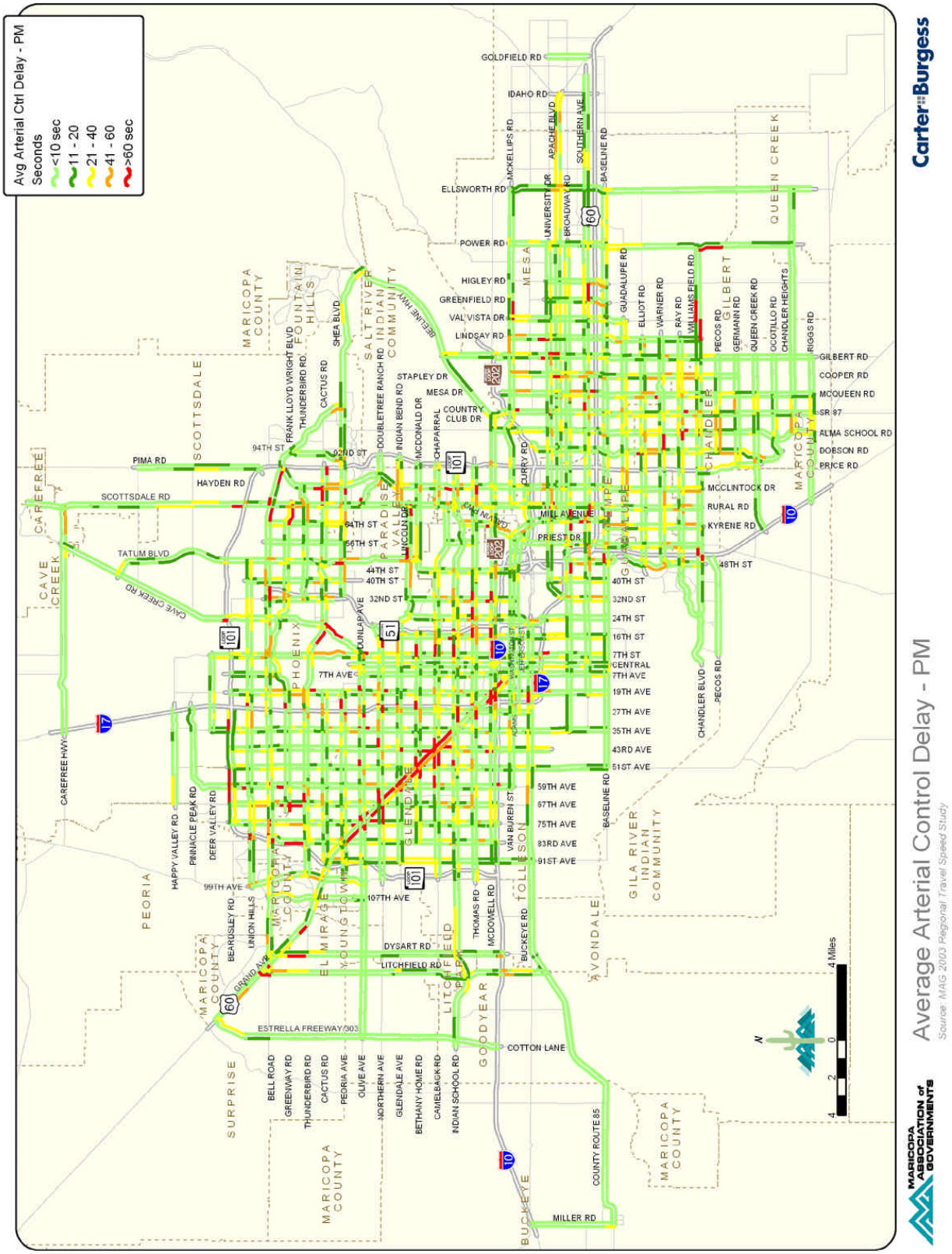


Figure 46A - Average Arterial Control Delay – PM Detail (Map 1 of 7)

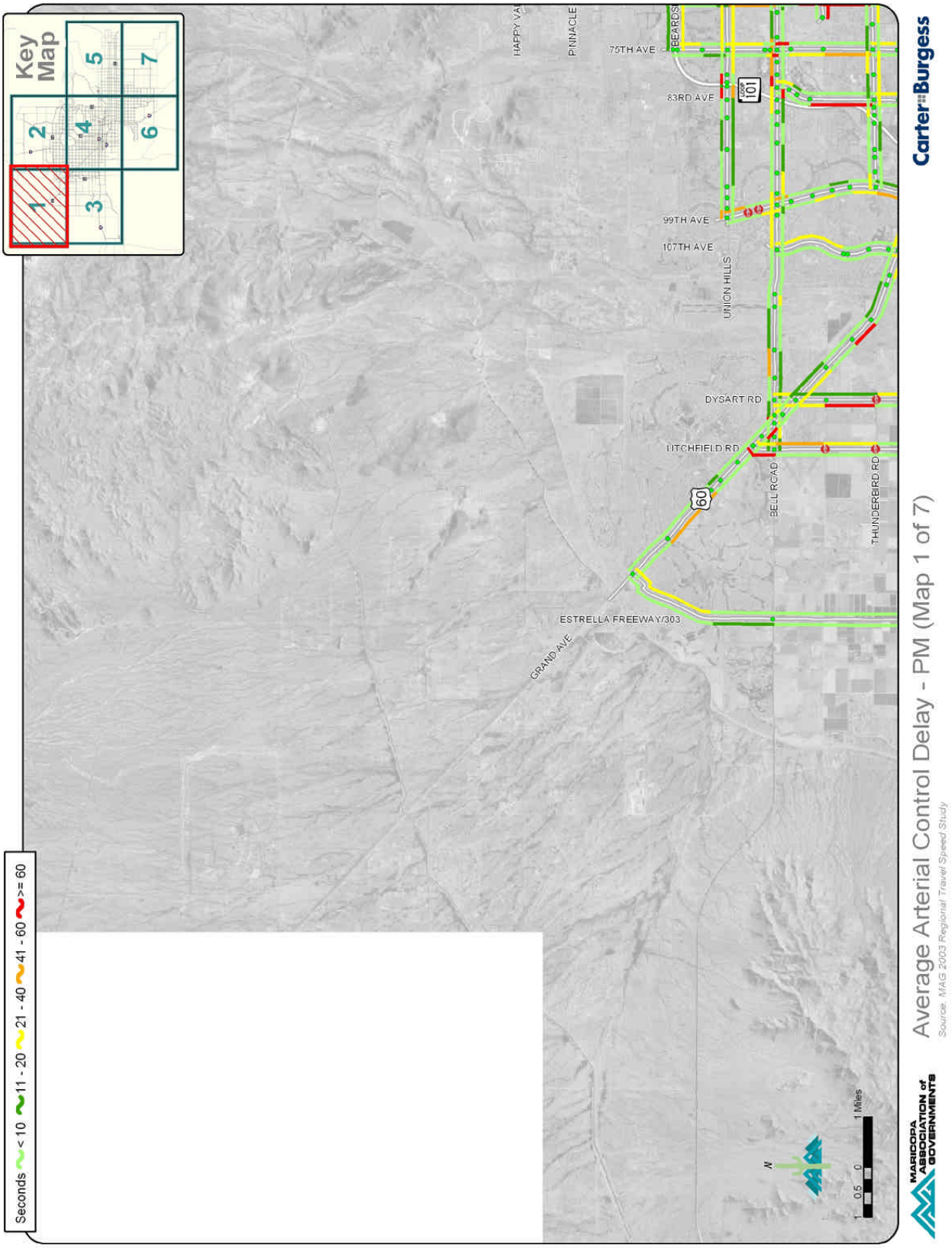


Figure 46B - Average Arterial Control Delay – PM Detail (Map 2 of 7)

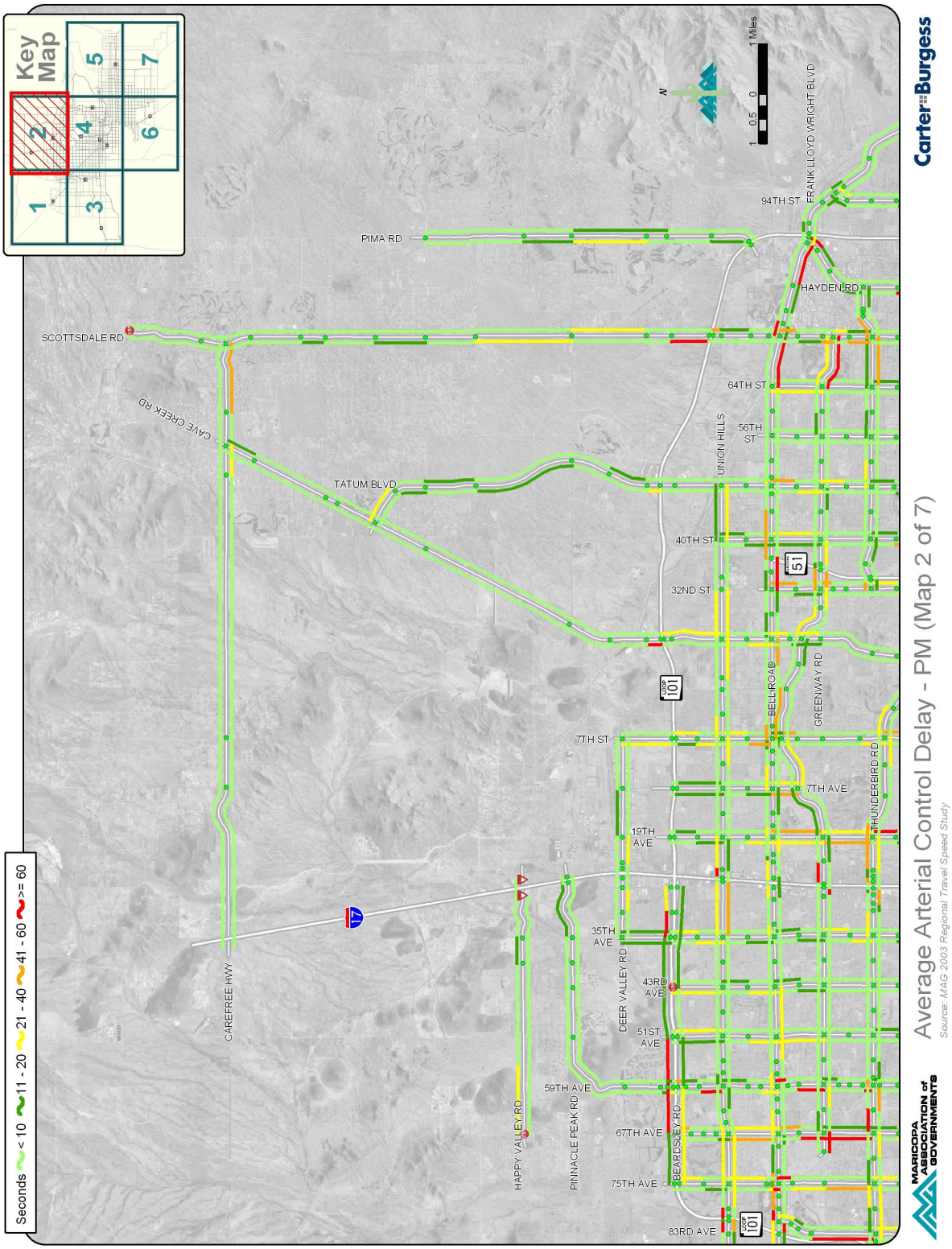


Figure 46C - Average Arterial Control Delay – PM Detail (Map 3 of 7)

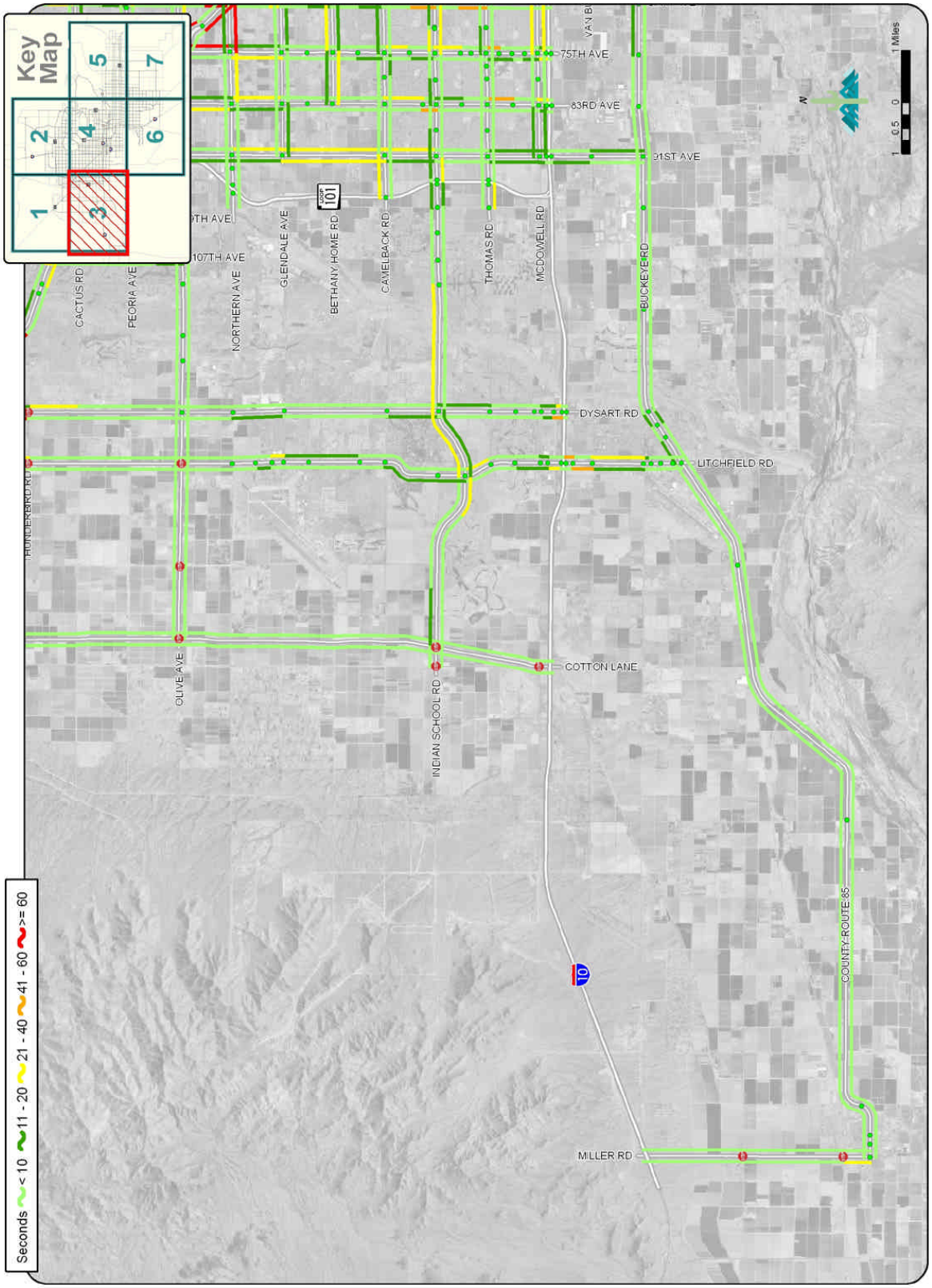


Figure 46D - Average Arterial Control Delay – PM Detail (Map 4 of 7)

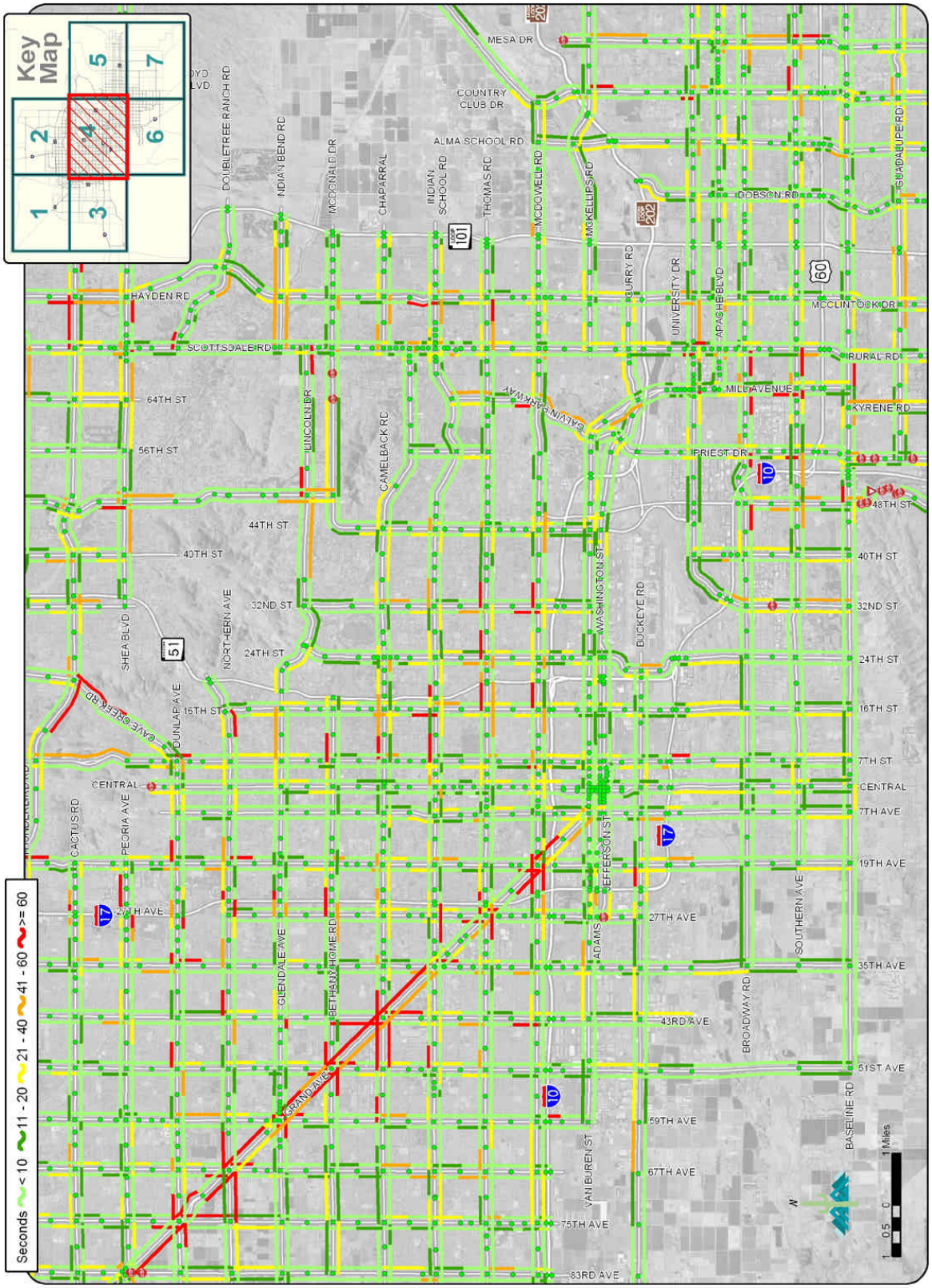


Figure 46E - Average Arterial Control Delay – PM Detail (Map 5 of 7)

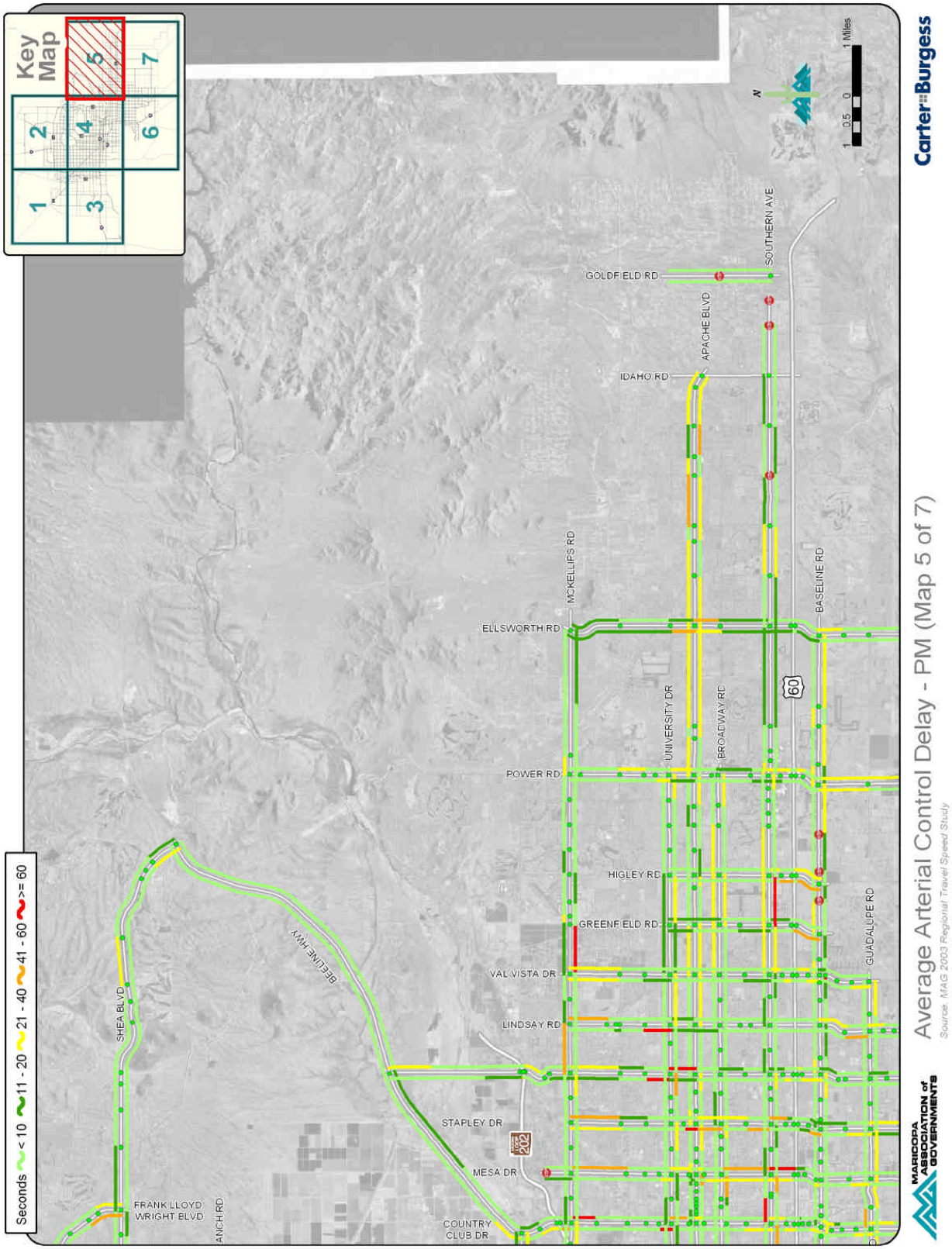


Figure 46F - Average Arterial Control Delay – PM Detail (Map 6 of 7)

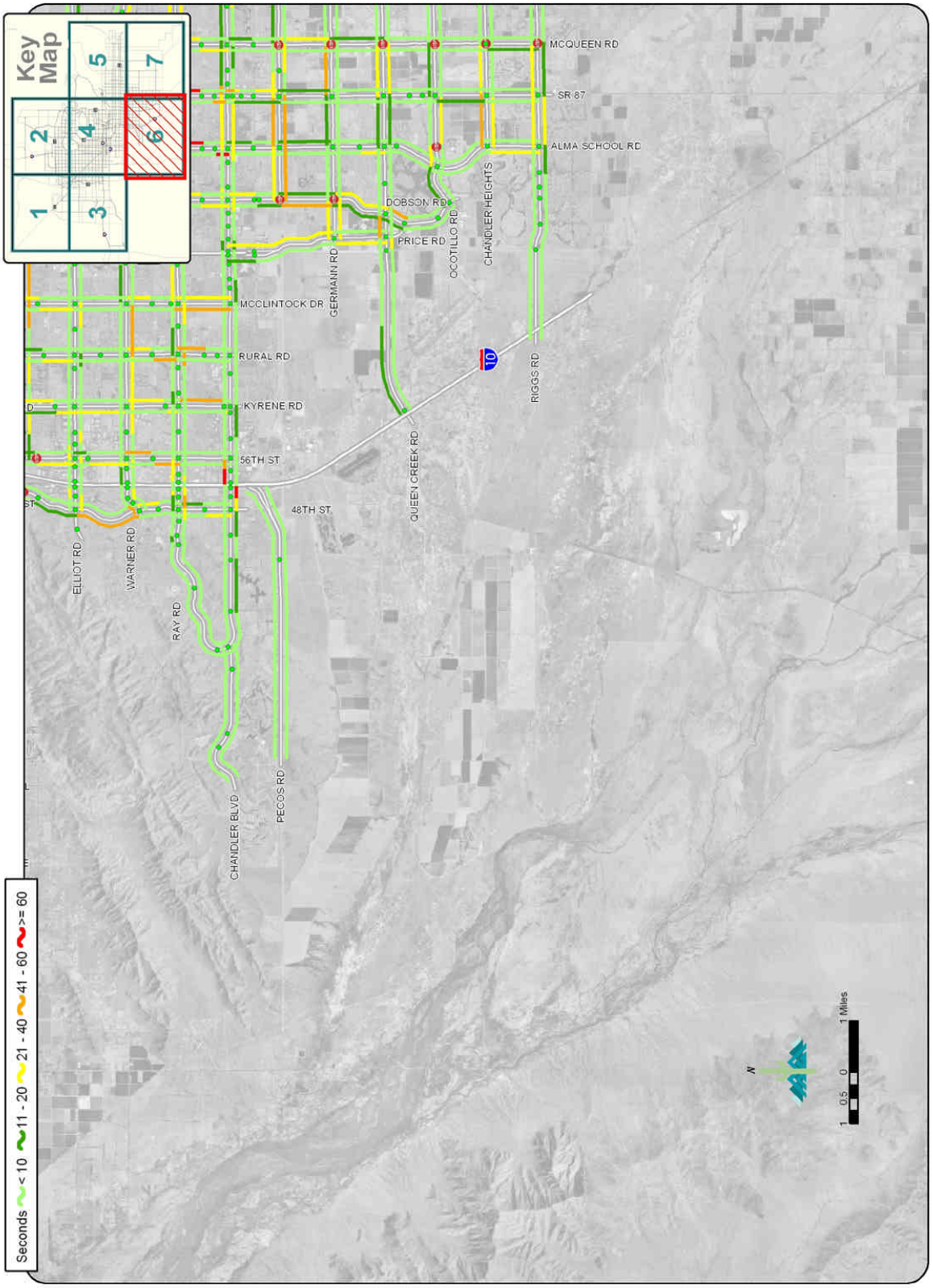


Figure 46G - Average Arterial Control Delay – PM Detail (Map 6 of 7)

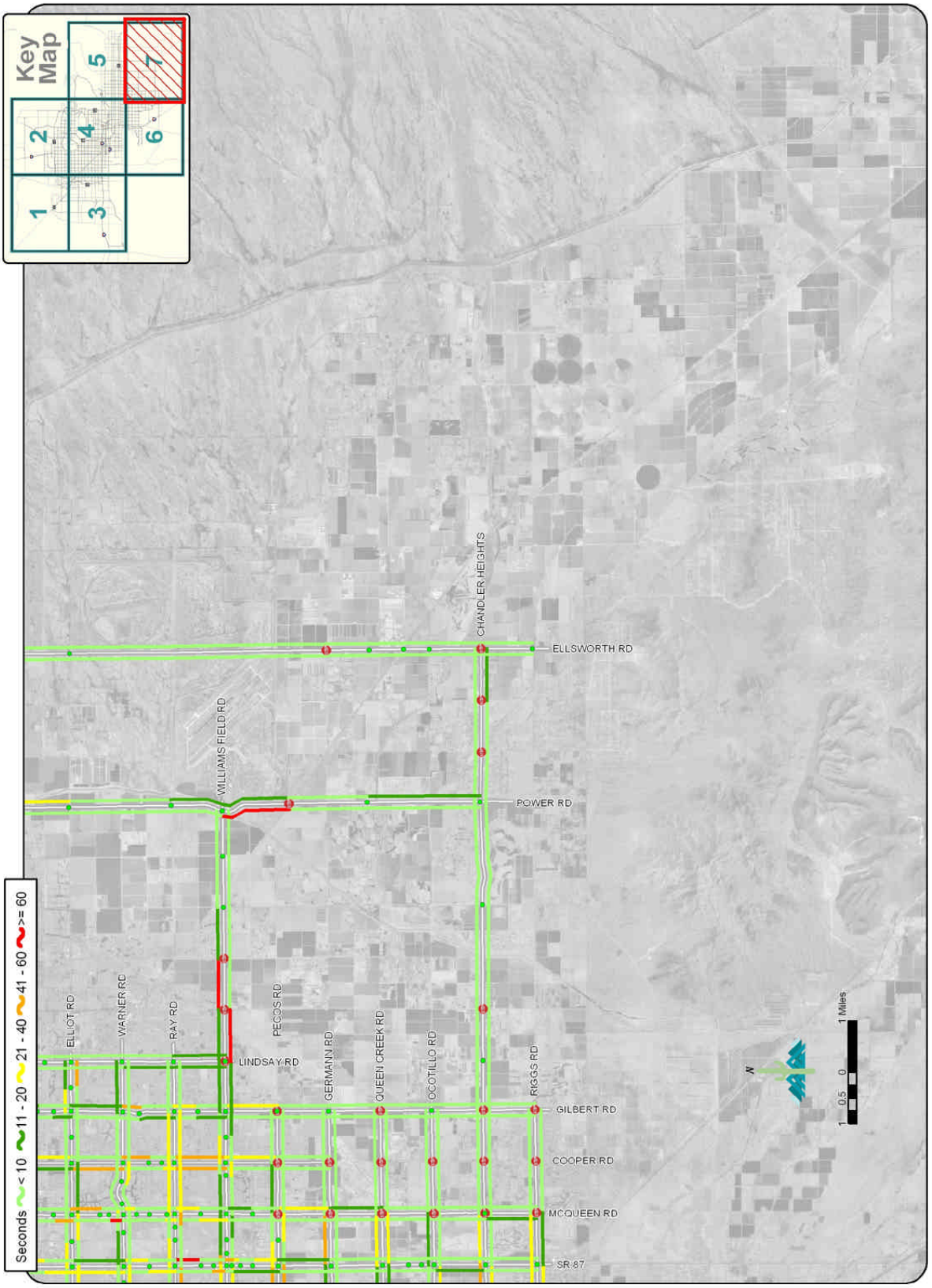


Figure 47 - Average Freeway Segment Delay per Mile – AM

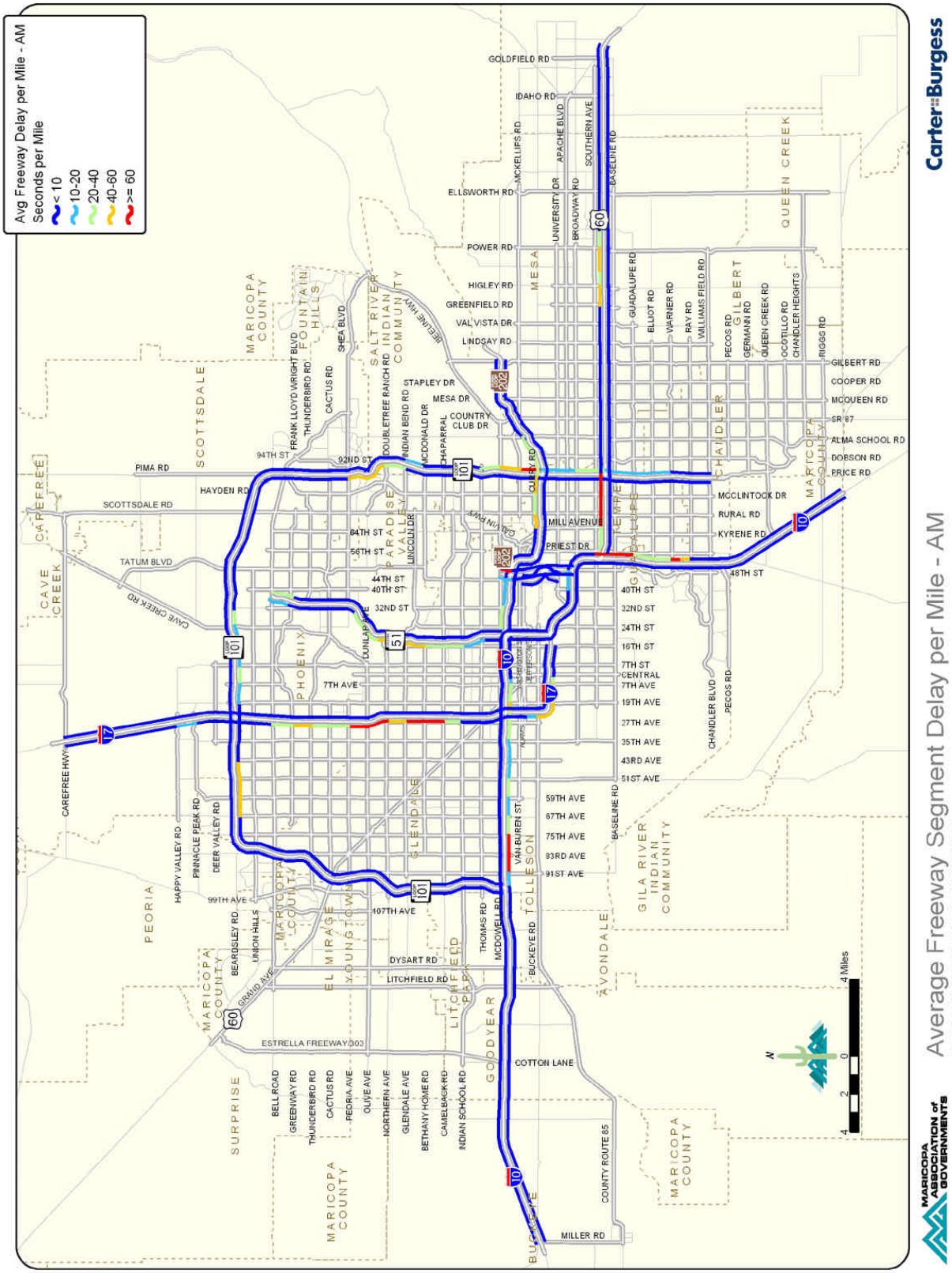


Figure 48 - Average Freeway Segment Delay per Mile – Mid-Day

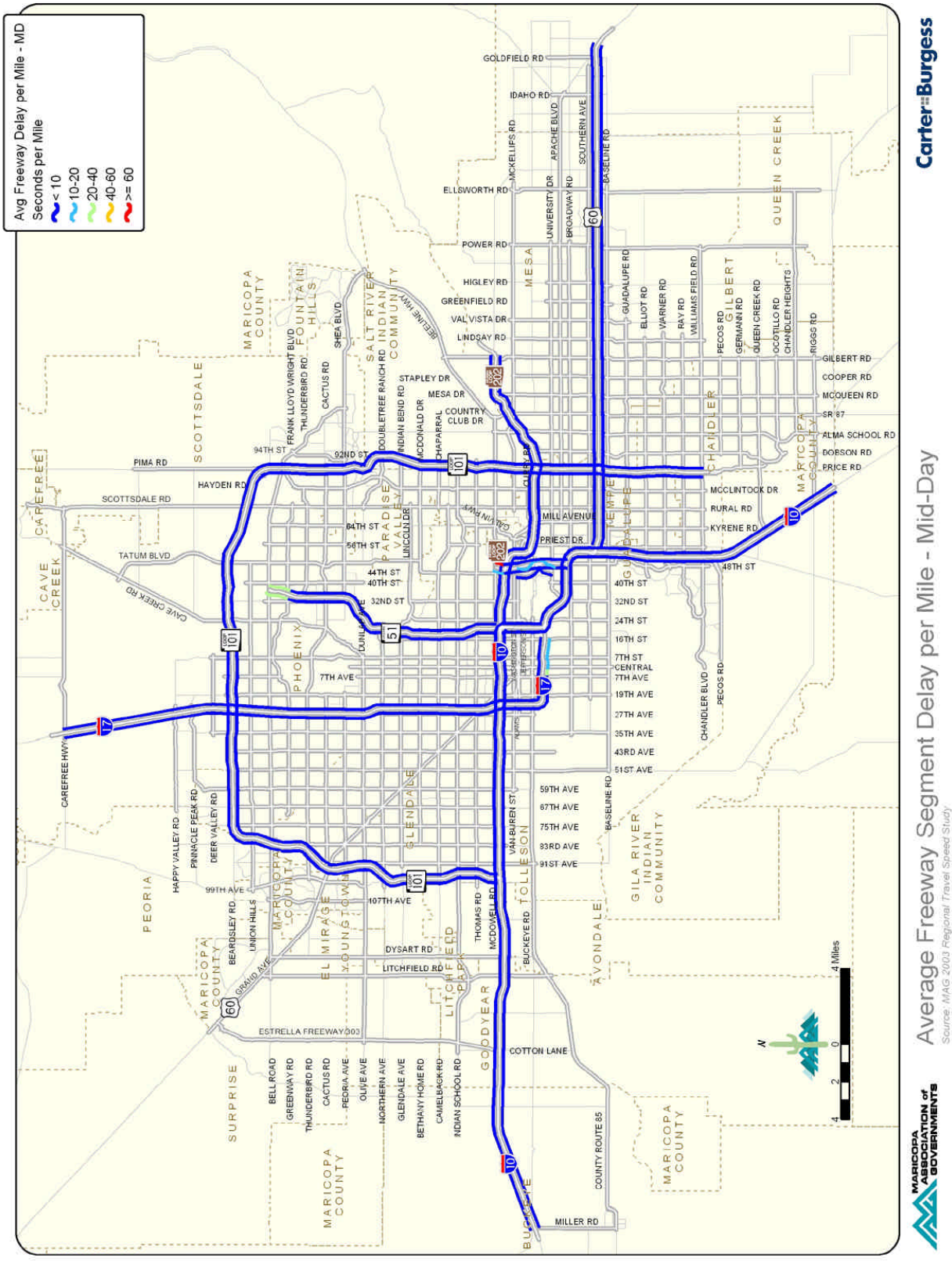
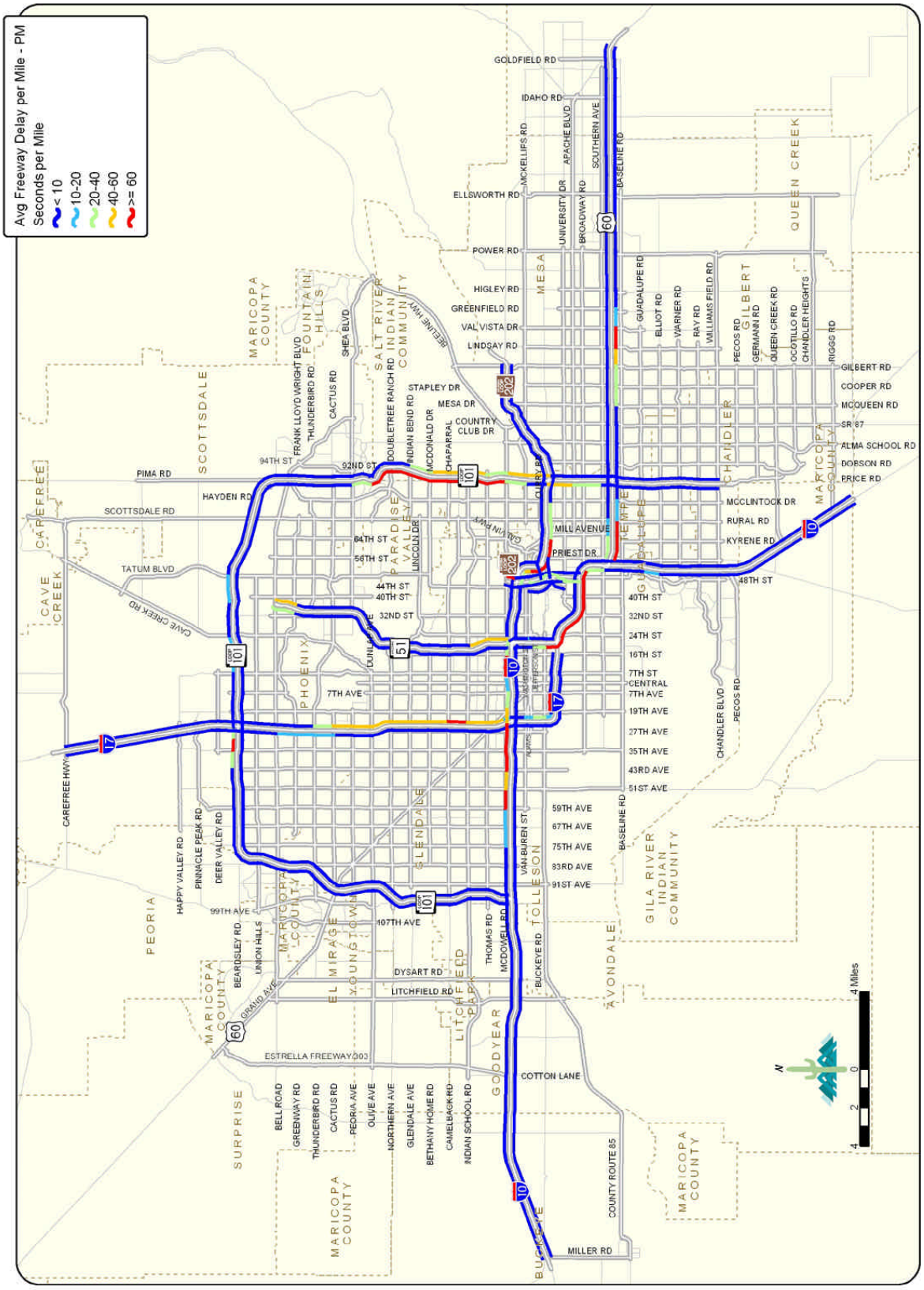


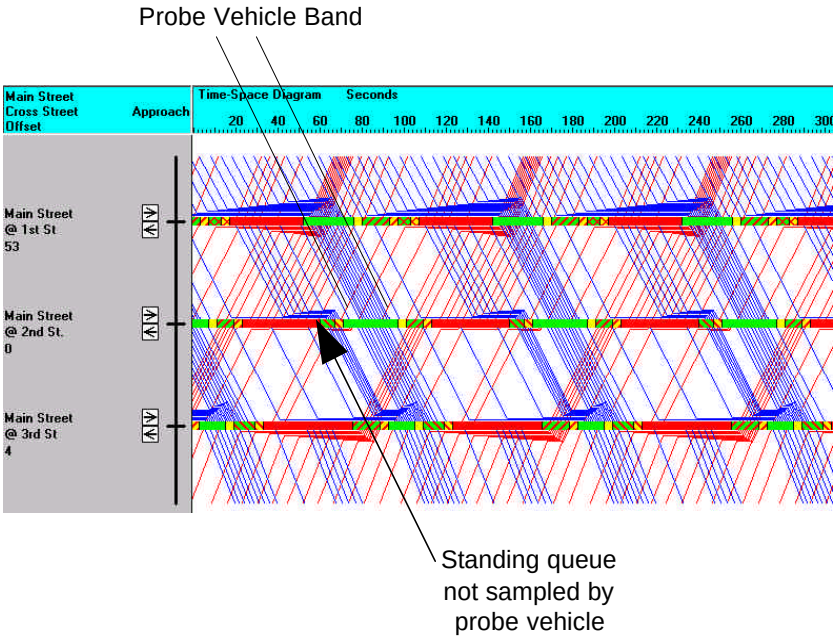
Figure 49 - Average Freeway Segment Delay per Mile – PM



5.2 Queue Measurement

One of the questions that has been raised regarding probe GPS data, is "can queue length be measured." Strictly, speaking the answer to this is no, because the sampling procedure will be biased. To illustrate this point, consider the time-space diagram shown in **Figure 50**. The figure shows the queuing that occurs in a coordinated system. The blue and red lines represent the two directions on an arterial. The multi-color bands are the signal phasing and cycle lengths.

Figure 50 – Time Space Diagram

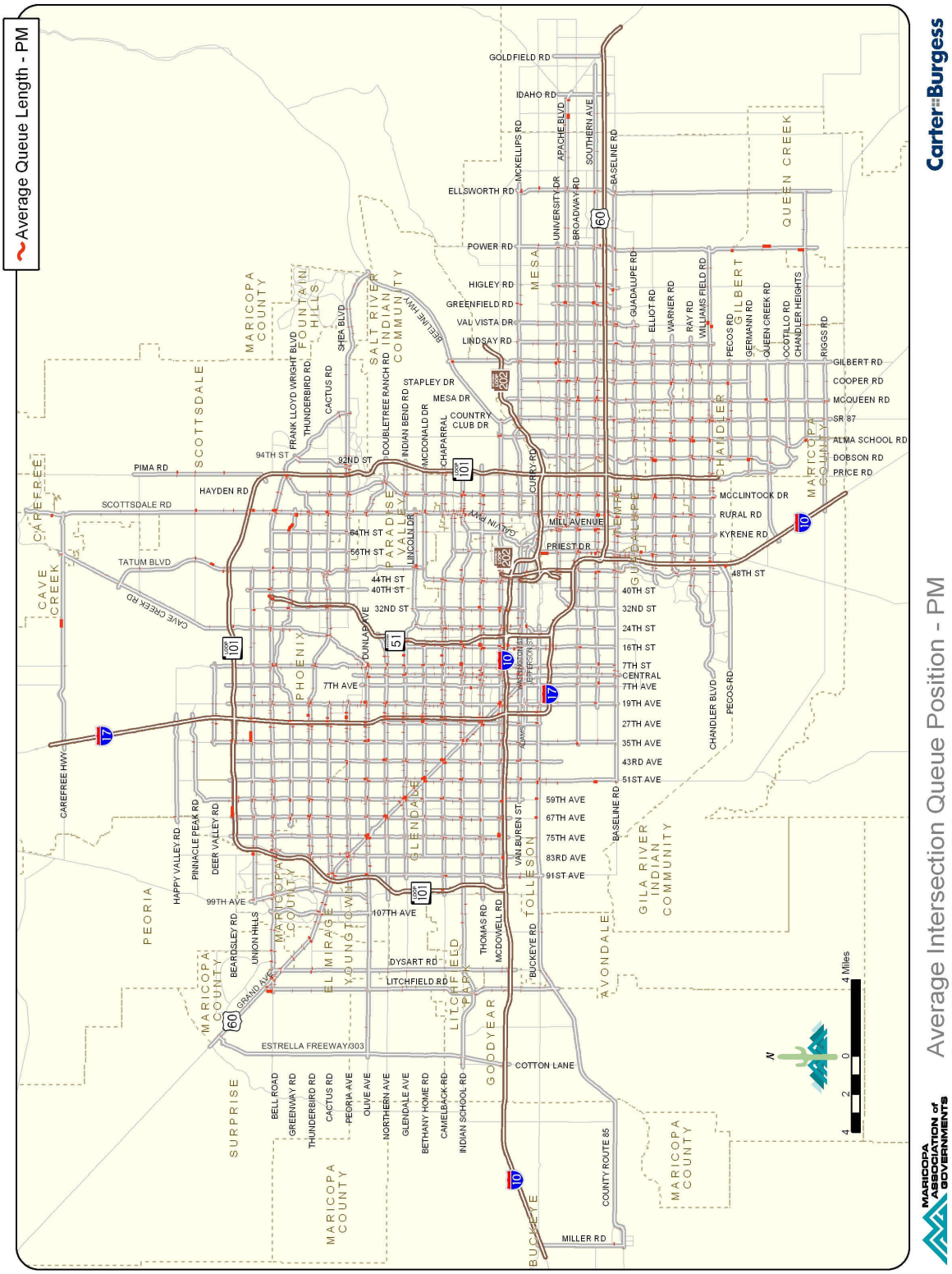


As one can observe, a probe vehicle would only sample the queue at the middle intersection during periods bounded by the bands defined by start of through green and end of through green at an upstream signal. In general, this is less then 50% of the cycle. However, it is certainly feasible to report maximum, minimum, and average queue length from the travel runs. This data would be based upon queue length observed by through arterial traffic, it does not reflect queue conditions that may occur for minor movements. Queues measurements would be subject to the following assumptions:

- The back of the queue would be defined as the point where the speed fell below 3 mph and the queue continues to the next cross street.
- Probe vehicles are uniformly distributed in the green band.

Figure 51 illustrates the average queue length.

Figure 51 – Average Intersection Queue Position – PM



6.0 Historical Speed and Traffic Delay Changes

In order to compare the results of the 2002-2003 study to previous studies, the data needed to be modified. For example, the 1993 study used longer segments than the 2002-2003 study, so segments in the 2002-2003 study were combined to create the same segments as in the 1993 study. As part of this study, average speeds from the 1979, 1986, and 1993 studies were geocoded into the GIS system.

Figures 52 and 57 are included for reference and depict the average speed found in the 1979, 1986, and 1993 studies respectively for the PM period. **Figures 58 and 59** illustrate the results of the coding of the historic network and represents changes in speeds since 1993 for those roads included in both studies.

7.0 Additional Illustrations of Performance

Figures 60-62 are included to illustrate other formats the data collected can be presented. They demonstrate the speed along the route and include the posted speed limit. Each run is included to show the variability and also the resulting average by intersection segment and 0.1 mile segments.

Tables 26-28 summarize the resulting speed error at an 85% confidence interval for each of the time periods. They are further broken down by Area Type, Facility Type and Number of Lanes. As expected, the resulting error is greatest for the 6-leg arterial types due to the large variation in performance along Grand Ave.

To further highlight the variation in travel speeds between the peak periods and the mid-day travel runs, **Tables 29-30** show the percent difference. The PM peak period travel speeds are lower than the AM Peak Period and the travel speeds in the central part of the study area decrease more during the peak period than the outlying areas.

Figure 52 - Average Freeway Speed 1979 – PM

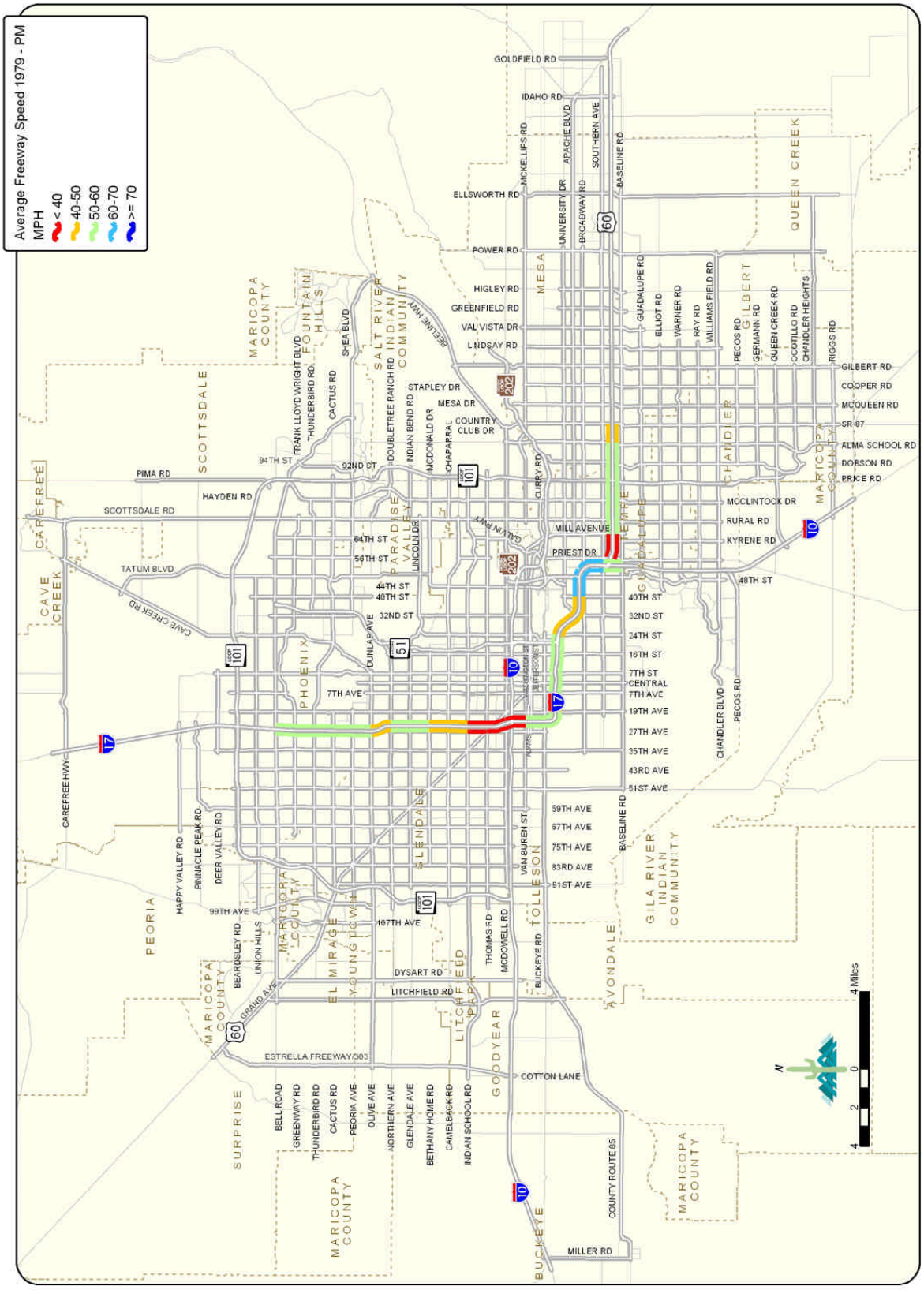


Figure 53 - Average Arterial Speed 1979 – PM

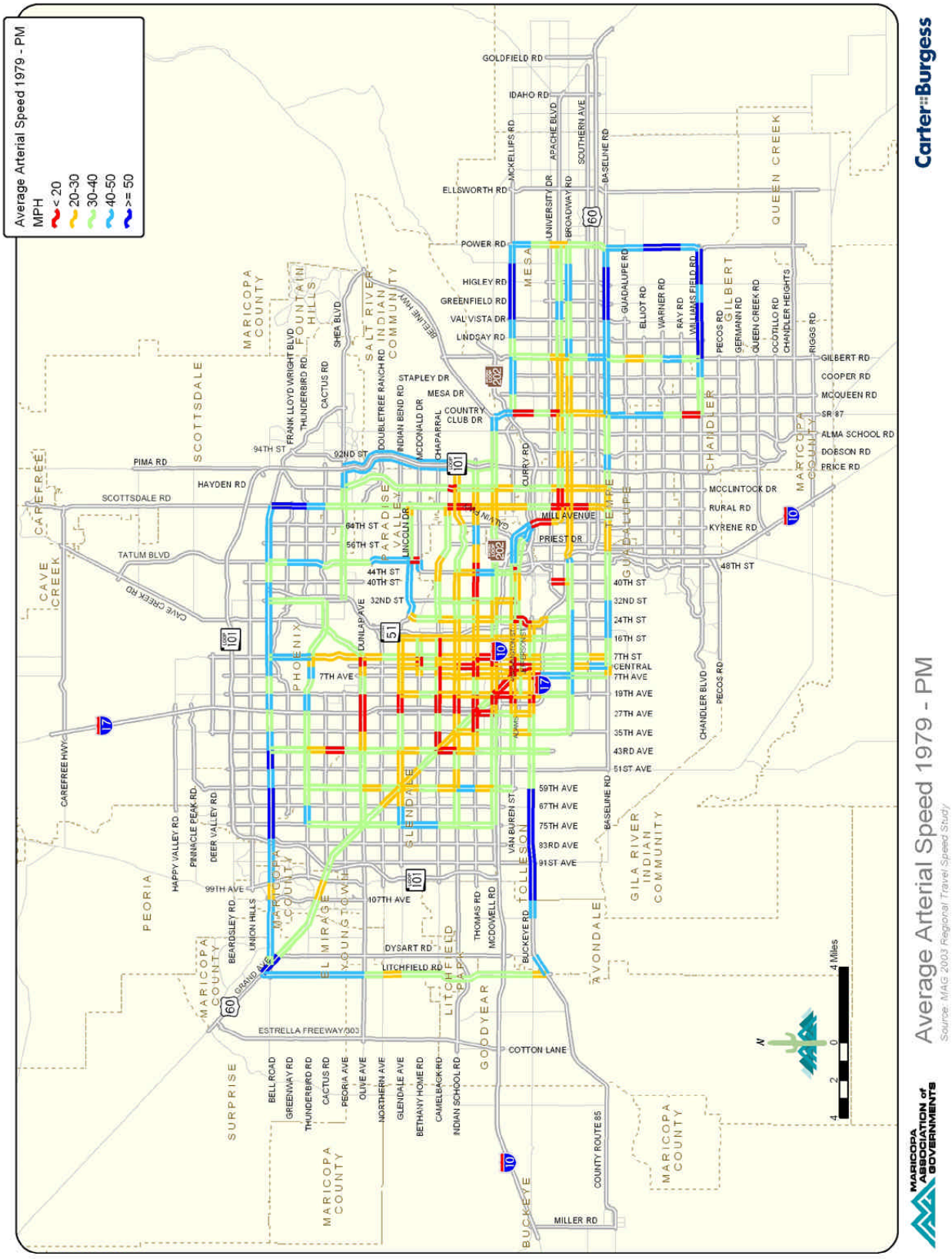


Figure 54 - Average Freeway Speed 1986 – PM

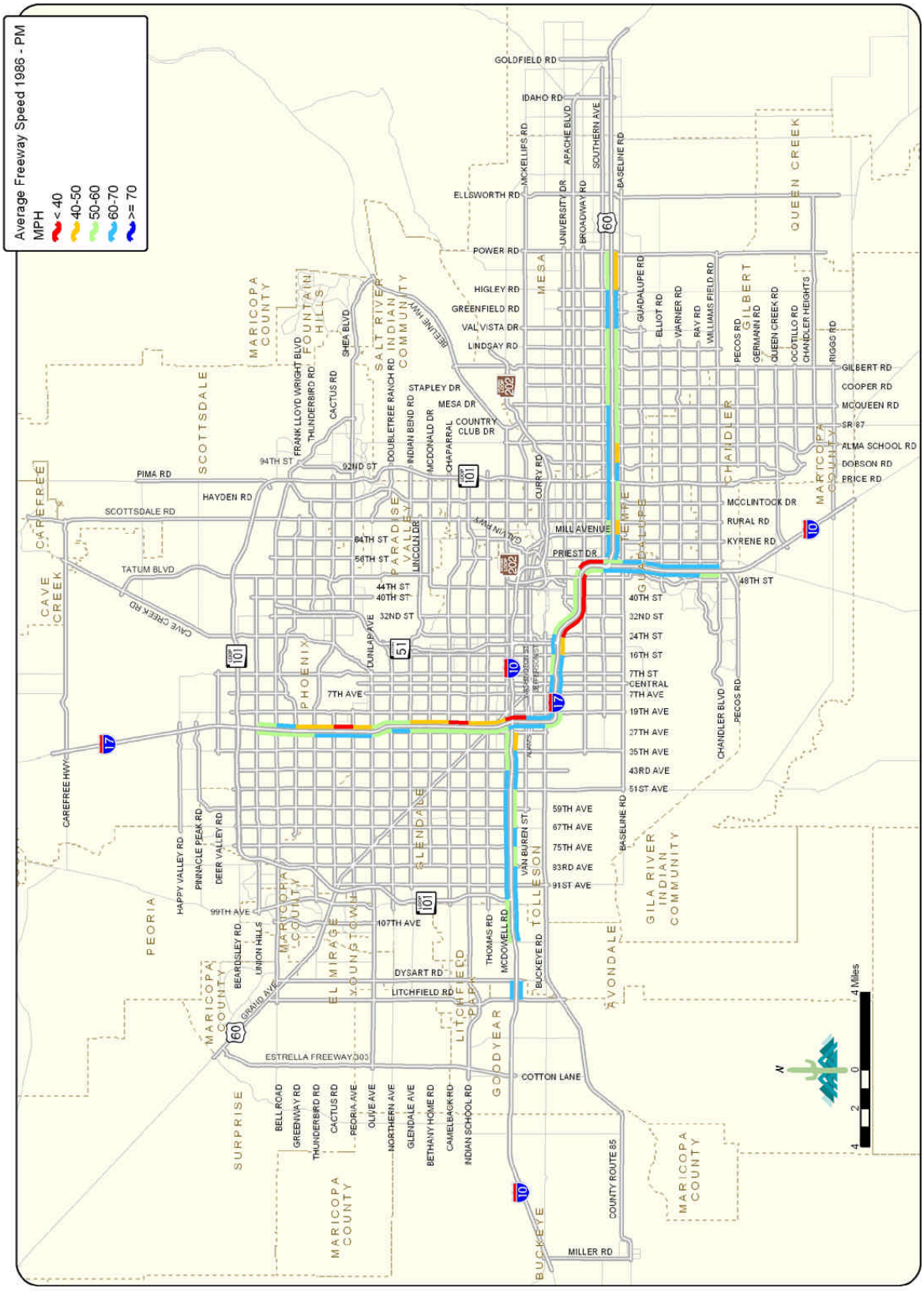


Figure 55 - Average Arterial Speed 1986 – PM

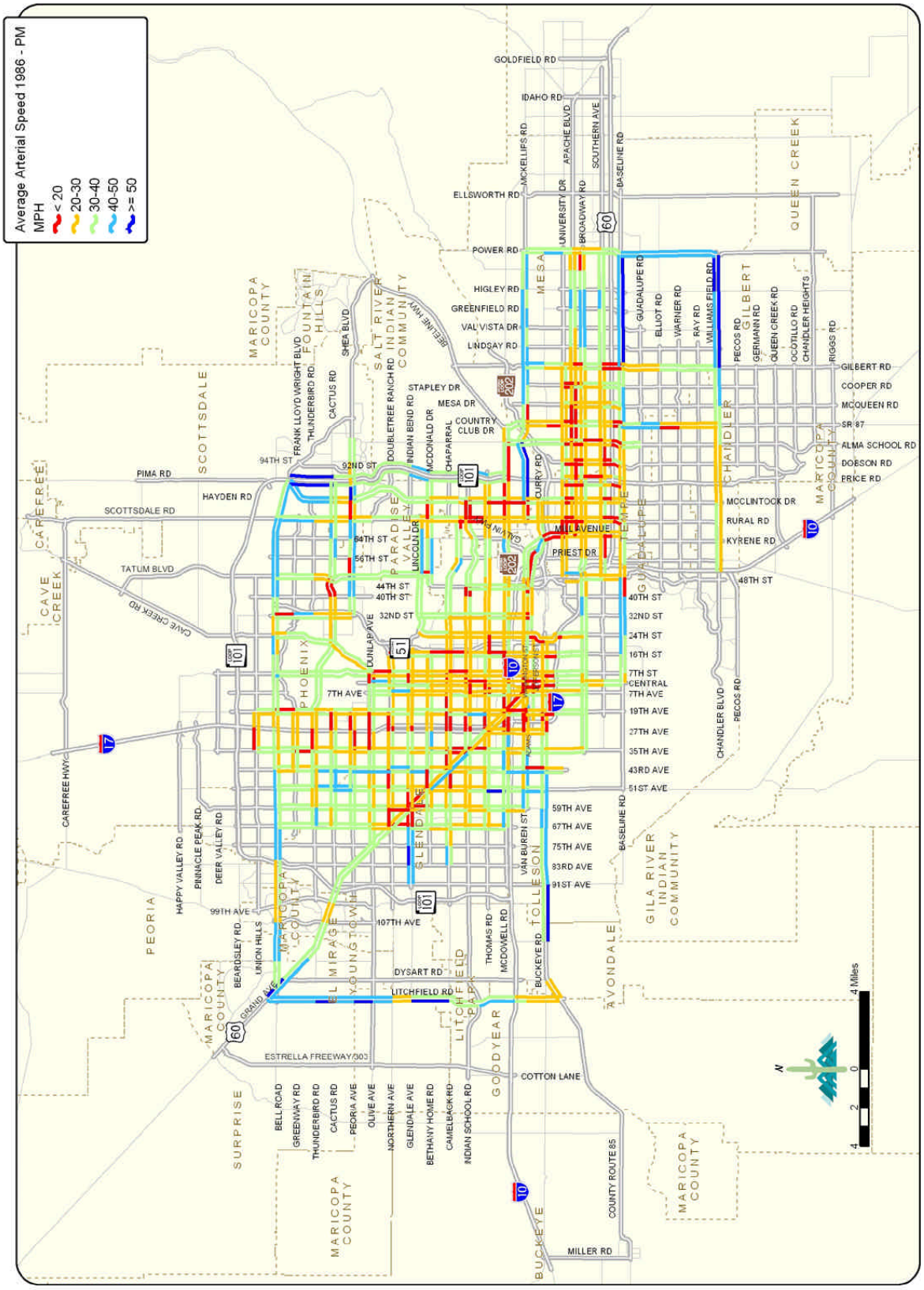


Figure 56 - Average Freeway Speed 1993 – PM

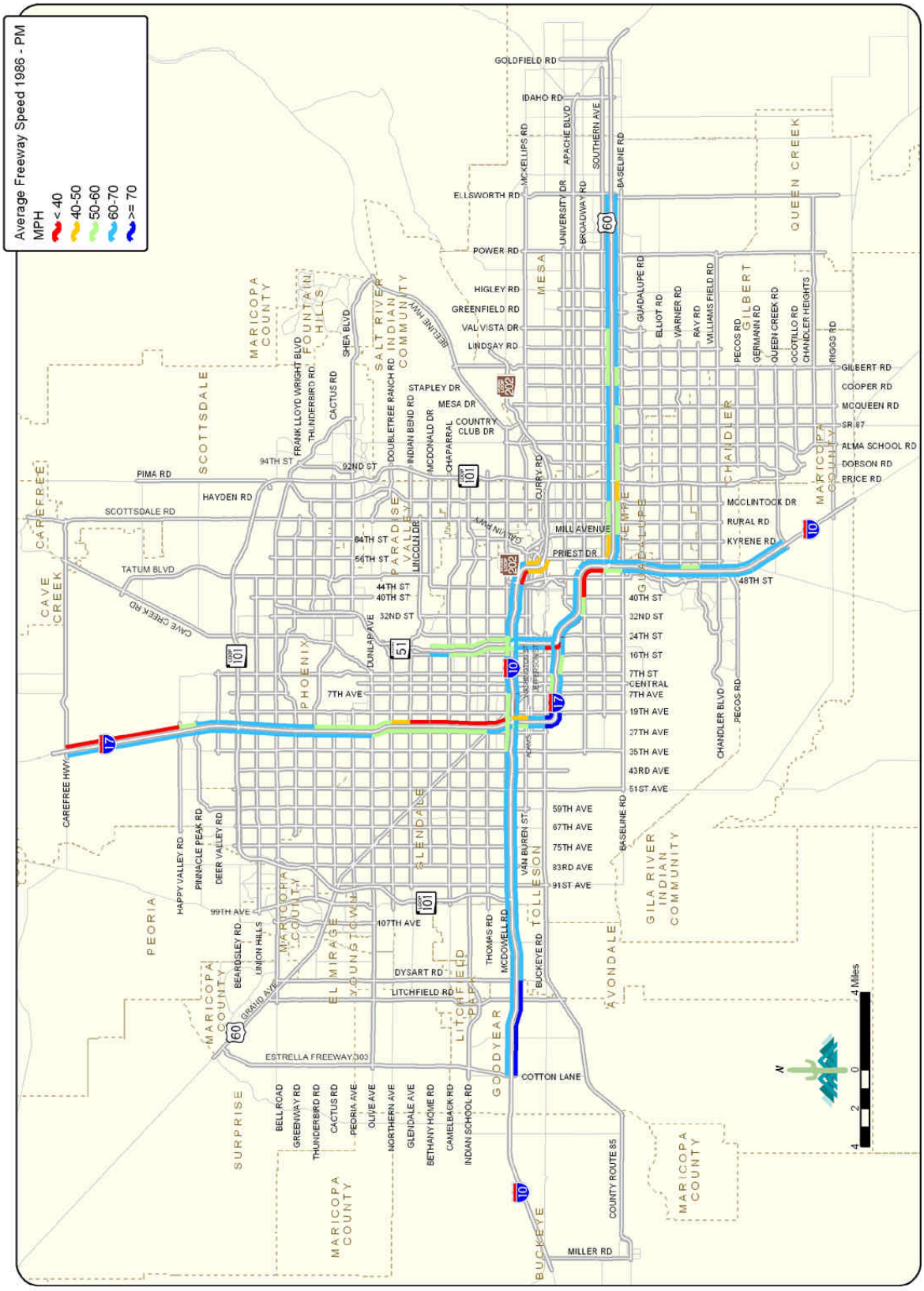


Figure 57 - Average Arterial Speed 1993 – PM

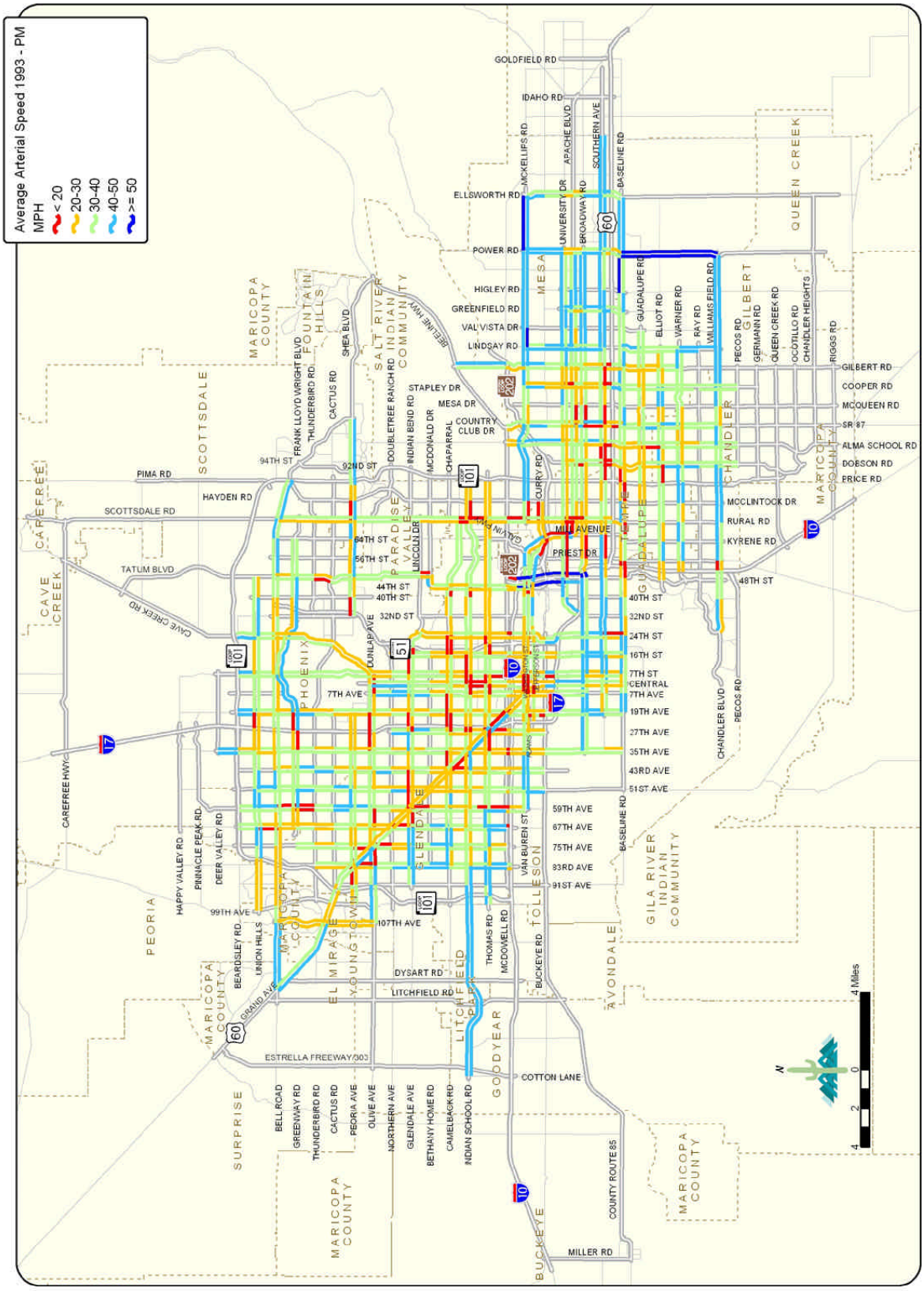


Figure 58 – Change in Average PM Freeway Speed - 1993 to 2003

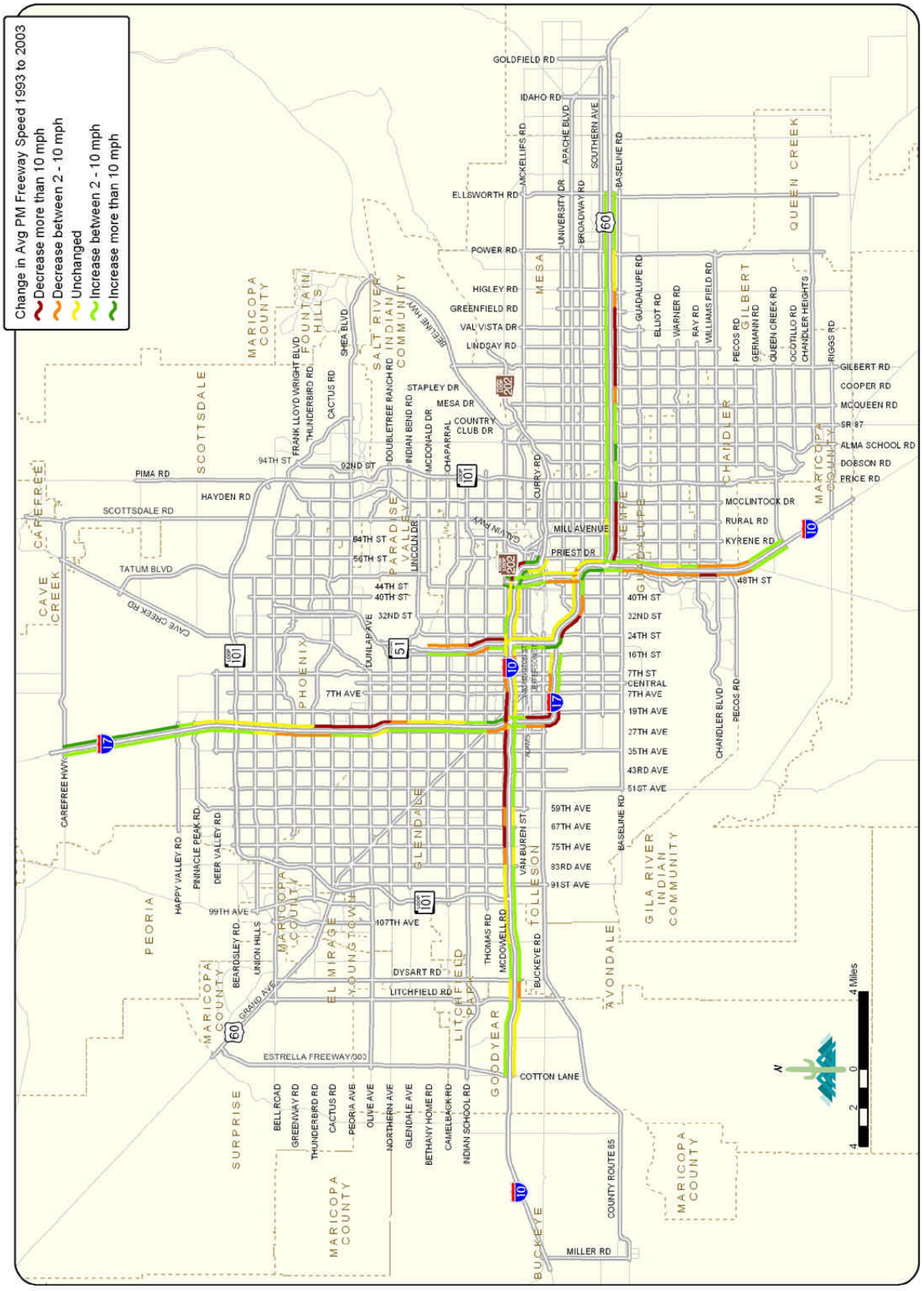


Figure 59 - Change in Average PM Arterial Speed - 1993 to 2003

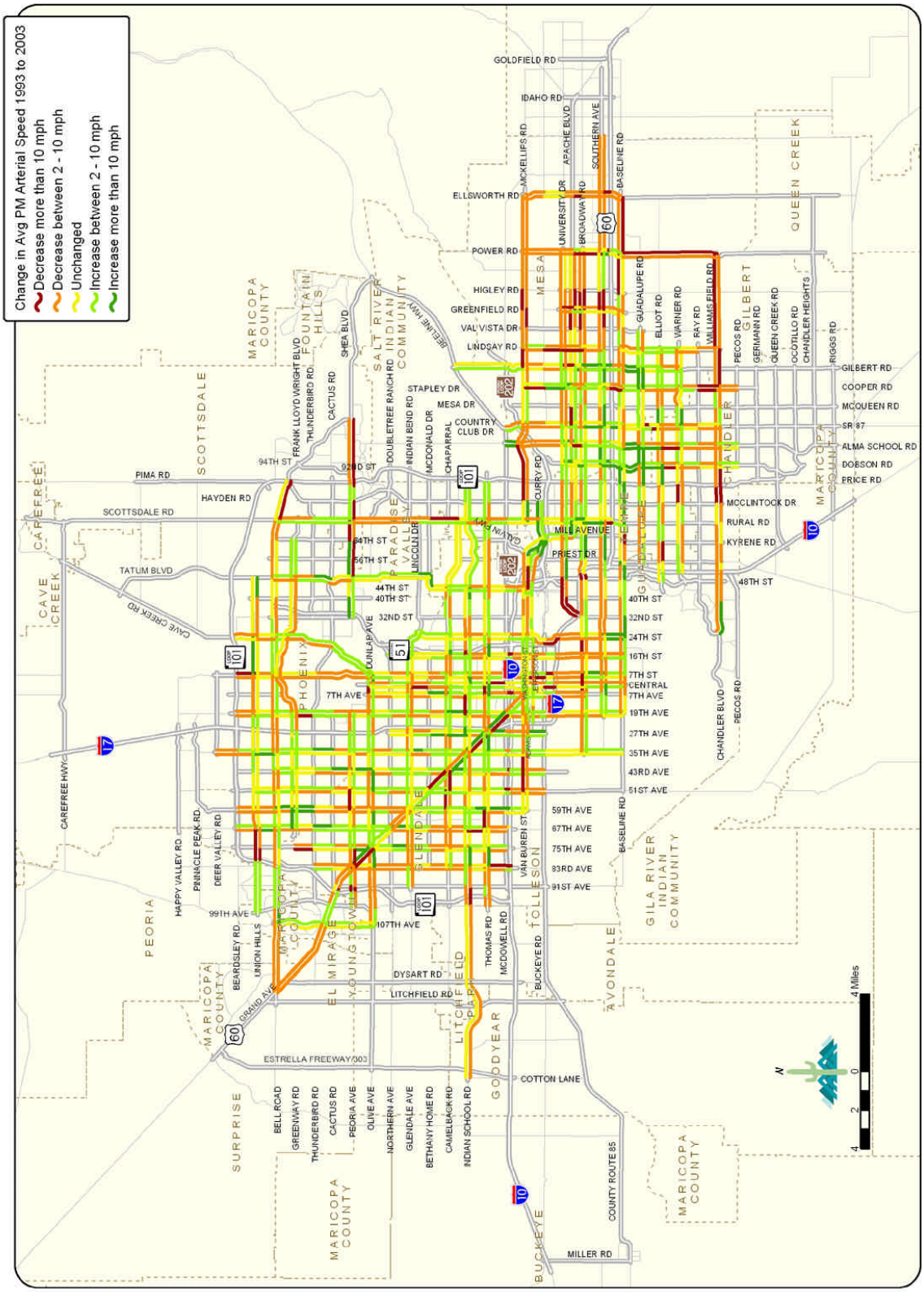


Figure 60- Indian School EB-AM

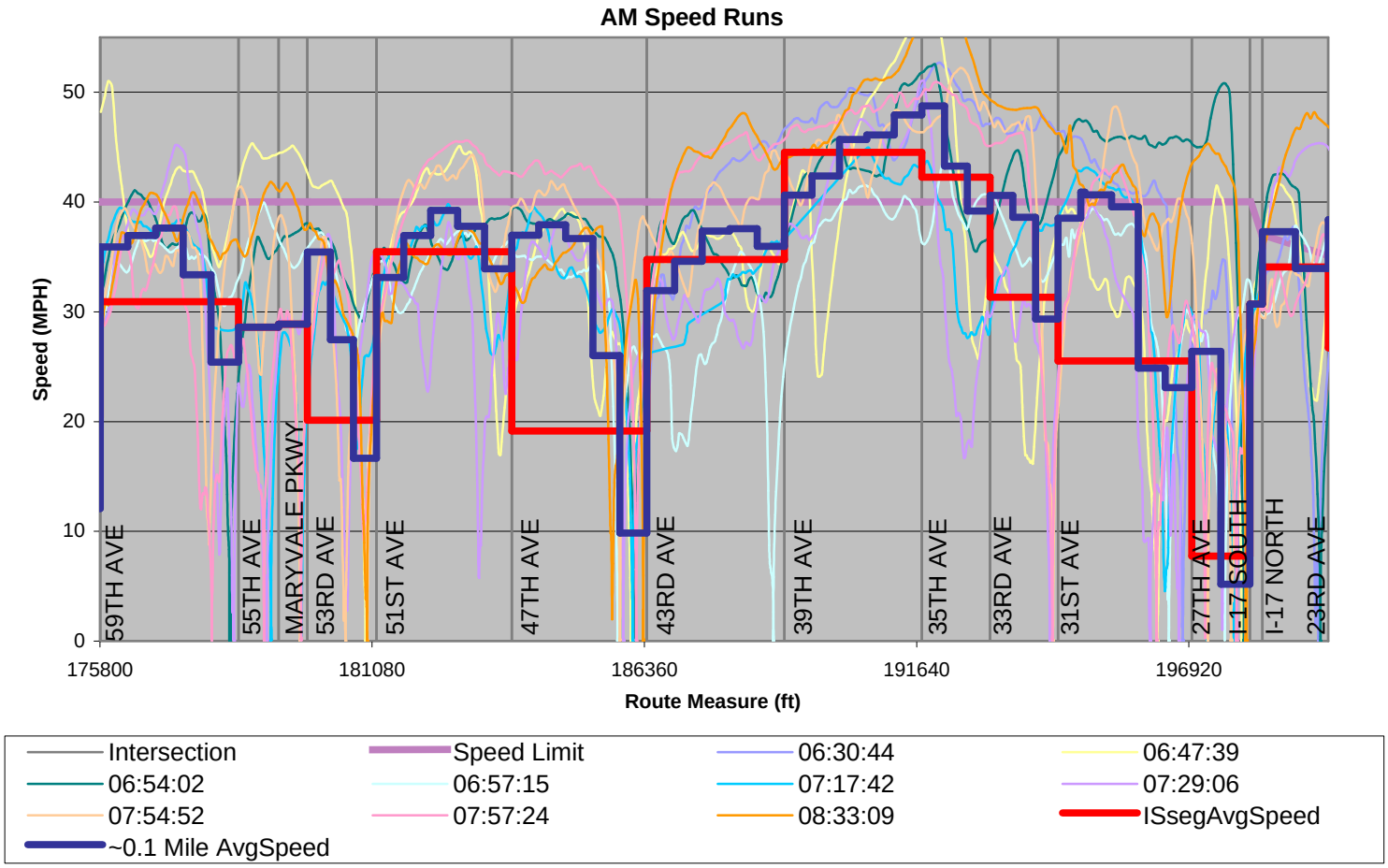


Figure 61- Indian School EB-MD

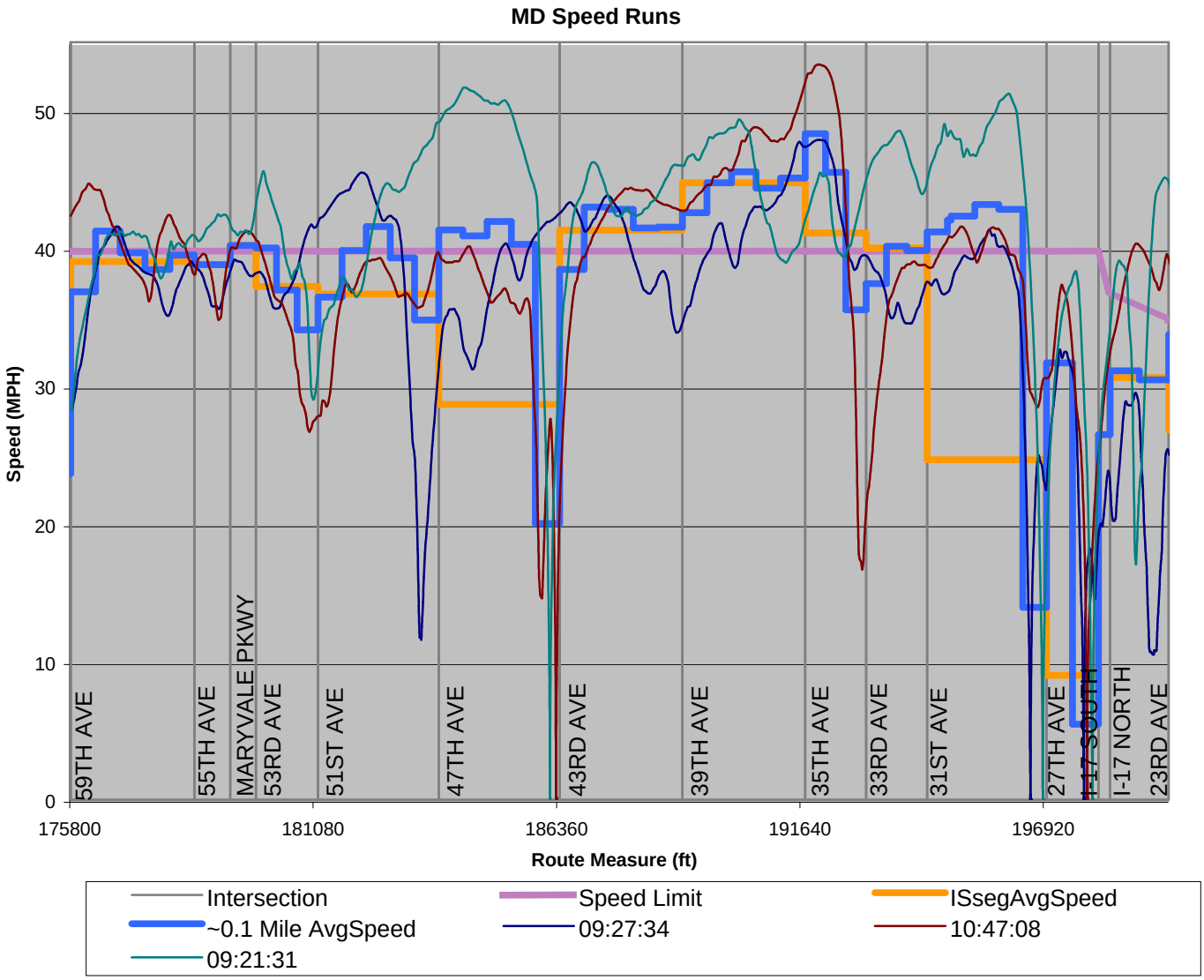


Figure 62- Indian School EB-AM & MD

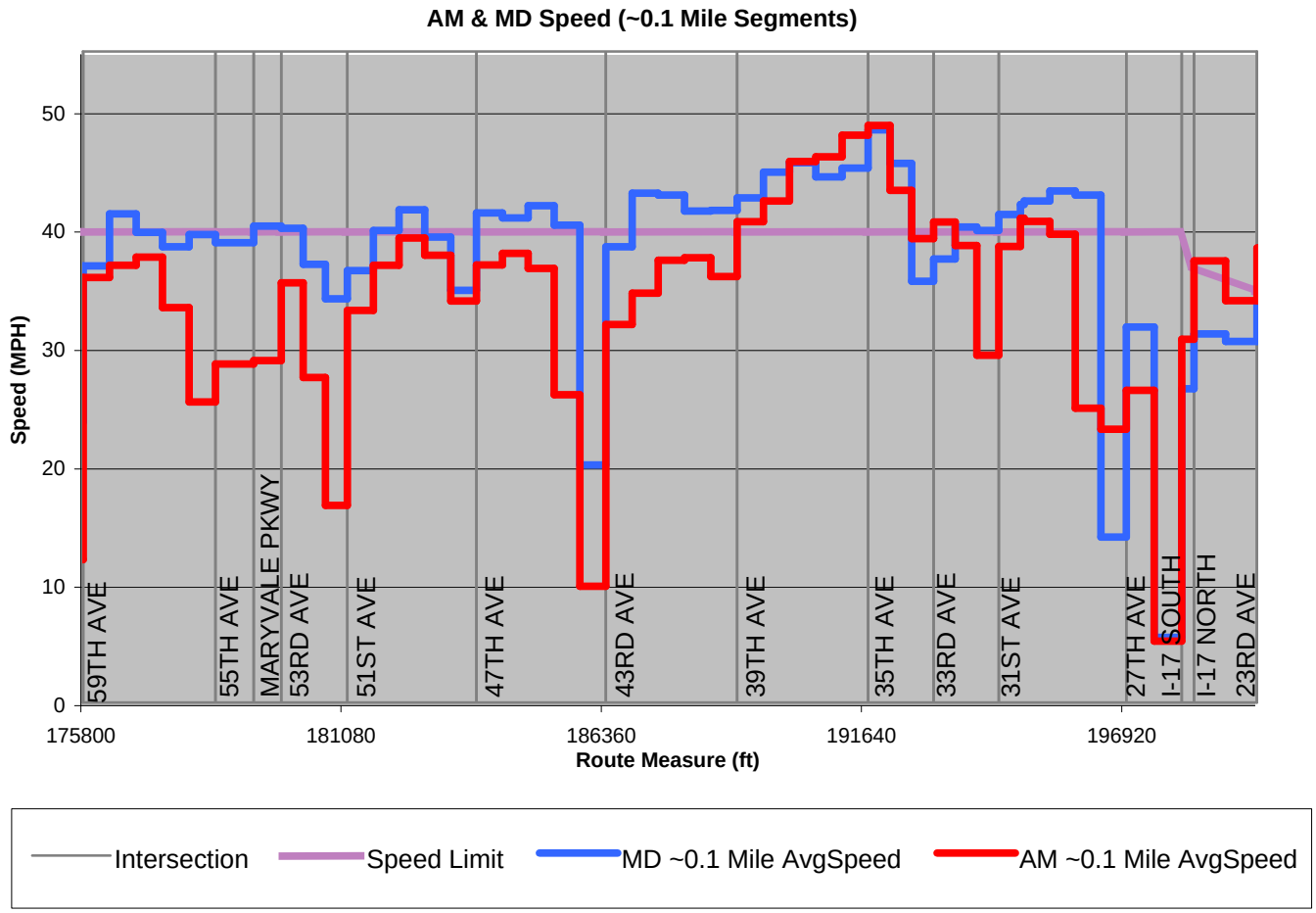


Table 25 – AM Speed Error at and 85% Confidence Level

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	3.29	3.78	-	7.30	4.55	4.50
CBD (Outlying)	All	2.97	3.26	5.47	5.97	4.45	4.29
Mixed Urban	All	2.99	3.68	-	-	4.31	4.21
Suburban	All	4.35	2.83	4.11	6.04	4.16	4.01
Rural	1	-	-	2.91	-	3.14	3.09
	2 or more	-	3.46	3.01	-	4.45	4.05
ALL		3.04	3.35	3.41	6.11	4.26	4.12

Table 26 –MD Speed Error at and 85% Confidence Level

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	-	3.62	-	7.26	4.44	4.39
CBD (Outlying)	All	-	3.26	5.47	5.93	4.40	4.22
Mixed Urban	All	-	3.50	-	-	4.27	4.16
Suburban	All	-	2.86	4.01	6.27	4.08	3.94
Rural	1	-	-	2.98	-	3.10	3.08
	2 or more	-	3.40	2.90	-	4.40	3.89
ALL		-	3.30	3.35	6.14	4.20	4.05

Table 27 –PM Speed Error at and 85% Confidence Level

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	3.27	3.82	-	7.35	4.59	4.56
CBD (Outlying)	All	2.97	3.28	5.47	5.95	4.45	4.30
Mixed Urban	All	3.06	3.66	-	-	4.29	4.20
Suburban	All	4.35	2.81	4.17	6.30	4.13	3.98
Rural	1	-	-	2.93	-	3.14	3.10
	2 or more	-	3.45	2.98	-	4.47	4.02
ALL		3.06	3.34	3.47	6.16	4.25	4.12

Table 28 –AM Weighted Average Percent of Mid-Day Speed

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	-	91.3%	-	98.3%	96.8%	96.8%
CBD (Outlying)	All	-	87.1%	93.1%	89.0%	93.6%	92.9%
Mixed Urban	All	-	90.3%	-	-	95.4%	94.9%
Suburban	All	-	97.3%	99.8%	93.7%	97.0%	97.2%
Rural	1	-	-	103.1%	-	97.0%	98.5%
	2 or more	-	97.9%	97.7%	-	98.3%	98.1%
ALL		-	92.2%	100.4%	90.7%	95.6%	95.4%

Table 29 –PM Weighted Average Percent of Mid-Day Speed

Area Type	Lanes	Functional Classification					
		HOV	Freeway	Expressway	6 Leg Arterial	Major Arterial	ALL
CBD	All	-	76.6%	-	80.6%	87.6%	86.1%
CBD (Outlying)	All	-	83.2%	90.3%	81.7%	88.1%	87.8%
Mixed Urban	All	-	92.0%	-	-	91.0%	91.5%
Suburban	All	-	97.4%	99.9%	94.3%	95.8%	96.4%
Rural	1	-	-	104.5%	-	100.2%	101.2%
	2 or more	-	92.5%	99.5%	-	97.8%	95.8%
ALL		-	90.5%	101.2%	84.1%	92.2%	92.4%

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