Appendix D
Travel Modeling Methods

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List of Abbreviations

Ave.	Avenue
Blvd.	Boulevard
BNSF	Burlington Northern Santa Fe (Railway)
CBD	Central Business District (downtown)
CDOT	Colorado Department of Transportation
CSU-Pueblo	Colorado State University-Pueblo
Dr.	Drive
GIS	geographic information systems
HBO	home-based other
HBW	home-based work
HOV	high-occupancy vehicle (carpool, vanpool, bus, etc.)
I-25	Interstate 25
K-5	kindergarten through 5th grade
K-8	kindergarten through 8th grade
LOS	Level of Service
MPO	Metropolitan Planning Organization
NCHRP	National Cooperative Highway Research Program
NHB	non-home based
PACOG	Pueblo Area Council of Governments
PCC	Pueblo Community College
PEL	Planning and Environmental Linkages
Rd.	Road
SH	State Highway (numbered highway route)
SOV	single-occupant vehicle
St.	Street
TransCAD	Transportation Computer-Aided Design
US	United States (also numbered highway route)
VISSIM	*Verkehrs Im Stadt* (German for “traffic in towns”) Simulation
WPC	West Pueblo Connector
YMCA	Young Men’s Christian Association

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Appendix D. Travel Model

This Planning and Environmental Linkages (PEL) Study relies heavily on travel model forecasts to determine the need for improvements to US 50 and to evaluate which improvements will be most effective. This appendix summarizes the methods used to make those forecasts. In particular, it summarizes changes made to the Pueblo Area Council of Governments (PACOG) regional travel demand model specifically for this study. **Appendix E** contains a letter from PACOG's administrator agreeing with the changes that were made to the model.

What's in Appendix D?

Appendix D describes the methods used to forecast future traffic volumes and travel times. The PACOG model was used to forecast travel demand. The study team and PACOG updated and refined several model inputs, which are described here. The Synchro program was used to model delays at simple signalized and unsignalized intersections. VISSIM was used to model more complicated intersections and corridor-wide travel times.

D.1 What techniques were used to model travel for the US 50 West PEL Study?

Modeling travel for the US 50 Corridor involved modeling two travel components: the demand and the supply. Travel demand involves how many people and vehicles are traveling and where they are traveling. Travel supply addresses how the roadway network operates with a given travel demand.

PACOG provided the study team the regional travel demand model they use to perform their duties as the region's Metropolitan Planning Organization (MPO). The travel demand model follows the "four-step process" used by many MPOs throughout the country. Most of the travel demand model is implemented in TransCAD, which combines geographic information systems (GIS) capabilities with specialized transportation procedures. One part of PACOG's model uses custom software run from the Windows command prompt. The study team developed a spreadsheet-based post-model adjustment process to make the model forecasts more reliable. The PACOG model considers travel on a typical weekday during the school year because holidays can make travel patterns more complex.

The study team used two types of software to analyze and forecast traffic operations:

- **Synchro –** Implements procedures from the *Highway Capacity Manual* to calculate delay and levels of service (LOS) at signalized and unsignalized intersections. (Unsignalized intersections are controlled by stop or yield signs.)
- **VISSIM –** Simulates individual cars traveling on roads and can be used to evaluate conditions both at intersections and between them.

D.2 What are the steps of the travel demand model?

The PACOG travel demand model has four steps, with each step examining a different aspect of people's travel behavior:

1. Trip generation – Calculates how many trips there are
2. Trip distribution – Determines where trips start and end
3. Mode split – Determines how many trips travel by auto versus transit
4. Traffic assignment – Determines which roads drivers use to make a particular trip

During the process, the travel demand model considers different trip purposes—reasons people have for traveling—where travelers tend to have the same kind of behaviors. The trips by purpose are eventually added together to give the overall travel forecast. **Section D.3** identifies the trip purposes that the PACOG model uses.

The trip generation step calculates the number of trips based on land use characteristics, such as population and employment, because these represent the kinds of activities that people want to travel for. Because there are millions of places people could go in a city, the model simplifies its calculations by dividing the region into *zones*.

Technically, the trip generation step estimates the number of *trip ends* rather than the number of trips. The difference is that to plot trip ends and trips on a map, trip ends would be represented by points while trips would be represented by line segments. Therefore, every trip has two trip ends. “Origin” and “Destination” are two familiar labels given to trip ends. However, the trip generation step uses a different scheme that classifies trip ends into *productions* and *attractions*, which will be defined in **Section D.4**.

The trip distribution step links two trip ends to a whole trip. To do this, it considers an estimate of the travel time between two zones. Because people do not like to travel more than they have to, the model is more likely to connect close zones than more distant zones. Changing the model parameters can, therefore, change the average trip length (time) for the region. The trip distribution step produces a *trip table*, which can be thought of as having origins (or productions) along one axis and destinations (or attractions) along the other.

The mode split divides the trips based on whether the people making them use an auto or transit. Because not many people ride Pueblo Transit buses, the PACOG mode split model is fairly simple: a certain percentage of the trips by each trip purpose are assumed to use transit. (For school trips, the distance traveled is also a consideration.) In contrast, a region like the Denver metro area has a more complicated mode split model because it has to consider light rail in addition to buses, as well as whether people get to their stop by walking or using a park-and-ride lot. Because the Denver model is sensitive to factors such as the transit fare or the walking time—factors people would consider in making their travel decisions—its type of mode split model is sometimes called a *mode choice* model.

During the trip generation and distribution steps, the model works with trips made by people, called *person-trips*. The mode split step is also the first step where the model considers the number of trips made by vehicles because two or more people could be traveling together. Person-trips are converted to *vehicle-trips* by dividing by the average number of people in a car, called the *vehicle occupancy*, which also varies by trip purpose.

There are often many alternative routes between two points. The traffic assignment step considers how many drivers use each alternative route. Roads are represented by links in the model, and each route can be made up of several links. The traffic assignment step calculates link volumes by summing the number of vehicles that use a link for each possible alternative route.

Up until the traffic assignment step, the model considered trips for a 24-hour day. Of course, more people travel during some hours—rush hours—than others. Because a highway can handle only so many cars at a time—called its capacity—the traffic assignment step also needs to divide the daily trip table into smaller time periods.

The PACOG model considers three time periods:

1. The morning rush hour
2. The evening rush hour
3. A 22-hour off-peak period

The PACOG model (and many others) uses sets of fixed percentages (called *time-of-day factors*) to divide the trips for each purpose into the three time periods.

D.3 What trip purposes does the travel demand model consider?

The travel demand model considers 14 trip purposes:

1. Low income home-based work (HBW) trips
2. Lower-middle income HBW trips
3. Upper-middle income HBW trips
4. High income HBW trips
5. Home-based elementary (K-8) school trips
6. Home-based secondary school trips
7. Home-based university trips to Colorado State University (CSU)-Pueblo and Pueblo Community College (PCC)
8. Home-based shopping trips
9. Home-based other (HBO) trips
10. Non-home-based (NHB), work-related trips
11. NHB other trips
12. Truck vehicle trips
13. Internal-external vehicle trips crossing into or out of Pueblo County
14. External-external vehicle trips crossing through Pueblo County without stopping

D.4 How are productions and attractions different from origins and destinations?

Using productions and attractions is a way to make the trip generation step more meaningful by classifying what factors are motivating the trip ends. For example, with HBW trips, productions are made at the home end, while attractions occur at the work end. Internal-External trips are produced at the county line (called an *external station*) and attracted to zones within Pueblo County.

The difference between productions and attractions versus origins and destinations can be seen by looking at how travel changes during the day. Consider someone making a work commute. In the morning, this person travels from home (the production end) to work (the attraction end). Because an origin is always the place a traveler is leaving from, in the morning, the origin corresponds to the production, and the destination corresponds to the attraction. However, the reverse is true for the evening trip when the commuter returns from work (attraction) to home (production). Converting productions and attractions to origins and destinations occurs during the time of day procedures that are part of the traffic assignment step.

D.5 What changes affecting trip generation were made?

Three changes affecting trip generation were made:

1. Updating university enrollment forecasts
2. Writing TransCAD code to track trips to and from *special generators*
3. Updating the internal-external and external-external trip ends

D.5.1 What are the forecasts for university enrollment?

Table D-1 shows the fall 2005 (the "current" year for the PACOG model; it will be updated to 2010 as Census results are published) enrollment for CSU-Pueblo and PCC. The table also shows the corresponding enrollment forecast for 2035. In 2005, there were about 8,000 enrolled students in Pueblo County, with slightly more attending CSU-Pueblo. By 2035, enrollment at CSU-Pueblo is expected to roughly triple, while the total number of enrolled students increases to 18,000.

Table D-1. Current and Future University Enrollment

Institution	Zone	Fall 2005 Enrollment	Fall 2035 Enrollment Estimate
Colorado State University-Pueblo	193	4,198	12,415
Pueblo Community College	127	3,777	5,814
Total		**7,975**	**18,230**

Source: Department of Higher Education, Campus Institutional Research, compiled by PACOG, 2010.

D.5.2 What are special generators, and how are they included in the travel demand model?

Special generators are places with trip-making patterns that are not captured well by the standard trip rates and categories in the PACOG model. Because many of the special generators in the model are recreational, residents may be attracted to the open space available, rather than the people employed at that location.

Trips to special generators are added to the trips for their zones after the standard trip generation procedure has run. The model requires which zone the trips are being added to, and how many additional productions and attractions there are for each trip purpose. **Table D-2** shows the location of special generators and the number of trips they attract.

Table D-2. Special Generator Additional Attractions by Trip Purpose

Location	Zone	Additional HBO Attractions (Person-trips)	Additional NHB Work-Related Attractions (Person-trips)	Additional NHB Other Productions and Attractions (Person-trips)	Additional Truck Productions and Attractions (Vehicle Trips)	Additional Internal-External Attractions (Vehicle Trips)
City Park	157	3,040	1,600	1,743	16	784
Desert Hawk Golf Course (Pueblo West)	251	460	233	252	8	90
Elmwood Golf Course	156	480	240	260	5	110
Hollydot Golf Course (Colorado City)	278	690	350	378	13	135
Lake Minnequa	140	330	160	180	5	60
Lake Pueblo State Park:						
• Arkansas Point & Southshore Marina	241	415	219	224	5	57
• Juniper Breaks & Rock Canyon	216	402	211	217	5	55
• Northern Plains & Northshore Marina	242	703	370	379	10	98
Mineral Palace Park	23	1,090	560	590	30	190
Pueblo Country Club	80	400	200	225	10	70
Walking Stick Golf Course	192	500	260	270	10	90
YMCA*	163	2,212	1,148	1,229	29	455

Sources: *Barton-Aschman Associates, 1990; JFSA, 2010.*

Note: **YMCA special generator trips are applied to only 2035 forecasts.*

Abbreviations: *HBO = home-based other* *NHB = non-home based* *YMCA = Young Men's Christian Association*

Because adding special generator trips increases the county total of attractions, the productions for these trip purposes need to be factored up to match the new attraction total.

The PACOG model documentation written by Barton-Aschman (1995) described a spreadsheet that would add the extra trips to and from special generators, but the project team was not able to locate it. Instead, they wrote a new section of TransCAD code to make the same calculations.

D.5.3 What are the forecasts for internal-external and external-external trip ends?

The internal-external and external-external trips ends that the study team received appeared to be corrupted because the trip end volumes did not correspond to local experience. To correct this problem, PACOG used CDOT's historic traffic counts and forecasts of 2035 volumes for highways entering Pueblo County as a control total. The 1995 model documentation showed a split of external station volumes as being

- Three-quarters internal-external productions
- One-eighth external-external productions
- One-eighth external-external attractions

Using these fractions, the study team calculated the total number of internal-external and external-external trip ends, which are shown in **Table D-3** for 2005 and **Table D-4** for 2035.

Table D-3. 2005 Internal-External and External-External Trip Ends

Zone	Description	Total Daily External Station Volume (Vehicles)	Internal-External Productions (Vehicle Trips)	External-External Productions (Vehicle Trips)	External-External Attractions (Vehicle Trips)
307	I-25 North	31,500	23,624	3,938	3,938
308	US 50 East	6,800	5,100	850	850
309	US 50 Business East	3,000	2,250	375	375
310	I-25 South	12,200	9,180	1,525	1,525
311	SH 78 West	2,500	1,874	313	313
312	SH 96 West	2,700	2,024	338	338
313	US 50 West	8,300	6,224	1,038	1,038

Sources: CDOT compiled by PACOG, 2010; Barton-Aschman,1990; JFSA, 2010.

Table D-4. 2035 Internal-External and External-External Trip Ends

Zone	Description	Total Daily External Station Volume (Vehicles)	Internal-External Productions (Vehicle Trips)	External-External Productions (Vehicle Trips)	External-External Attractions (Vehicle Trips)
307	I-25 North	63,000	47,250	7,875	7,875
308	US 50 East	12,000	9,000	1,500	1,500
309	US 50 Business East	5,500	4,124	688	688

Zone	Description	Total Daily External Station Volume (Vehicles)	Internal - External Productions (Vehicle Trips)	External - External Productions (Vehicle Trips)	External - External Attractions (Vehicle Trips)
310	I-25 South	24,400	18,300	3,050	3,050
311	SH 78 West	4,500	3,374	563	563
312	SH 96 West	5,000	3,750	625	625
313	US 50 West	16,600	12,450	2,075	2,075

Sources: PACOG, 2010; Barton-Aschman, 1990; JFSA, 2010.

D.6 What changes affecting trip distribution were made?

The study team made three changes affecting trip distribution by:

1. Resolving conflicting information about terminal times
2. Updating the school trip pattern matrices
3. Updating the external-external trip pattern matrix

Terminal time is how long it takes to park or un-park a vehicle. Someone parking in his or her garage would need little time to do this. In other situations, such as parking downtown where it may be harder to find a spot, more time may be needed. Terminal time at each trip end is added to the travel time calculated from the TransCAD representation of the roadway network.

Trip distribution for the elementary and secondary school purposes, and for the external-external trip purpose, uses a growth factor method sometimes called the *Fratar Method*, which needs three inputs:

1. Productions by zone
2. Attractions by zone
3. A zone-to-zone pattern matrix

The growth factor method first multiplies the rows of the pattern matrix corresponding to productions to match the input productions. Then it multiplies the resulting columns of the pattern matrix to match the input attractions. By doing this several times, the method should eventually reach a trip table that matches both the input productions and attractions. All three inputs, of course, influence the final trip table.

D.6.1 How were terminal times determined?

The study team found two sources for terminal times. The TransCAD script that runs the PACOG model looks up terminal times in a database file with one record per zone. The study team received the terminal time files that were used for the I-25 New Pueblo Freeway Environmental Impact Statement. However, a review of those files uncovered some unexpected coding: some zones in outlying areas had high terminal times, while other zones near downtown had low terminal times. For example, a zone west of I-25 between Dillon Dr. and the future Platteville Blvd. Extension was coded having a 3-minute terminal time, while zone #30, just north of the Pueblo Convention Center had a 2-minute terminal time.

The second source of terminal times was the PACOG model documentation (1990), which gave terminal times by the area type of a zone. The area type describes the intensity of development within a zone. **Figure D-1** shows the area types for the zones in Pueblo County. **Table D-5** reproduces the terminal times by area type from the model documentation. Because the terminal time by area type table had a rational basis to it, the study team decided to use that approach and revised the database files used by TransCAD. The review also identified two zones between I-25 and Fountain Creek that were recoded from being in the Central Business District (CBD) area type to being in the CBD Fringe area type.

D.6.2 How was the school trip pattern matrix changed?

The study team reviewed the school trip pattern matrix to examine why the growth factor procedure was not converging during early model runs. The review then broadened to also examine the school enrollment fields in the socioeconomic database used for trip generation. The first part of the review identified the zones that had schools in them. The following changes were made to the socioeconomic database:

- Elementary enrollment in zone #127 was added to that of zone #128, corresponding to Carlile Elementary School
- Elementary enrollment in zone #132 was added to that of zone #133, corresponding to the Bessemer K-8 (for the model's purposes, "elementary enrollment" includes grades K through 8)
- Elementary enrollment in zone #138 was added to that of zone #204, corresponding to South Park Elementary School
- Elementary enrollment in zone #143 was added to that of zone #144, corresponding to Hellbeck Elementary School
- Elementary enrollment in zone #150 was added to that of zone #181, corresponding to Roncalli Middle School
- Elementary enrollment in zone #167 was added to that of zone #79, corresponding to Morton Elementary School
- Elementary enrollment in zone #185 was added to that of zone #168, corresponding to the Goodnight K-8
- Secondary enrollment in zone #230 was moved to zone #232, corresponding to the Pueblo Technical Academy, now the School of Engineering and Biomedical Science (Future model revisions should move this enrollment to zone #258 because the School of Engineering and Biomedical Science is now housed at Pueblo County High School.)

Area Type by Zone

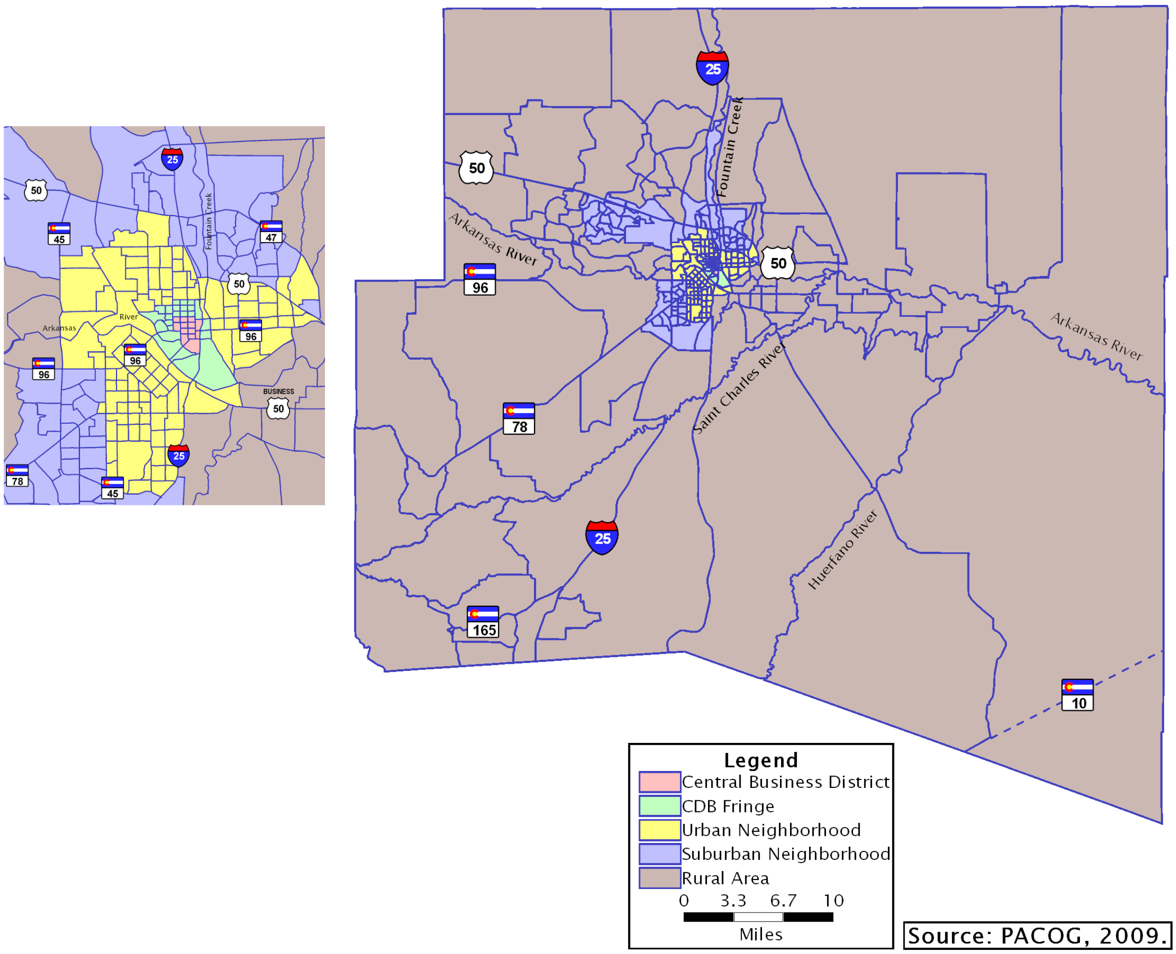


Figure D-1. Area Type by Zone for Pueblo County

Table D-5. Terminal Times by Area Type

Area Type Code	Area Type Description	Terminal Time (minutes)
10	Central Business District	3
20	Central Business District Fringe	2
30	Urban Neighborhood	1
40	Suburban Neighborhood	1
50	Rural Area	1

Source: Barton-Aschman, 1990.

After identifying zones with schools, the study team updated the elementary and secondary school trip pattern matrices. An inherent property of the growth factor process is that there must be a non-zero value in every cell of the pattern matrix where trips are expected. To determine likely school trip-making behavior, the study team reviewed the enrollment policies of the two major school districts in Pueblo County. District 60, which more or less corresponds to the city of Pueblo, has open enrollment. District 70, which serves much of Pueblo County outside the city limits, has designated feeder areas for each of its schools. **Figure D-2** shows these feeder areas for elementary (K-5) schools, **Figure D-3** for middle schools, and **Figure D-4** for high schools. However, District 70 also has some alternative or charter schools that may draw from all over the district.

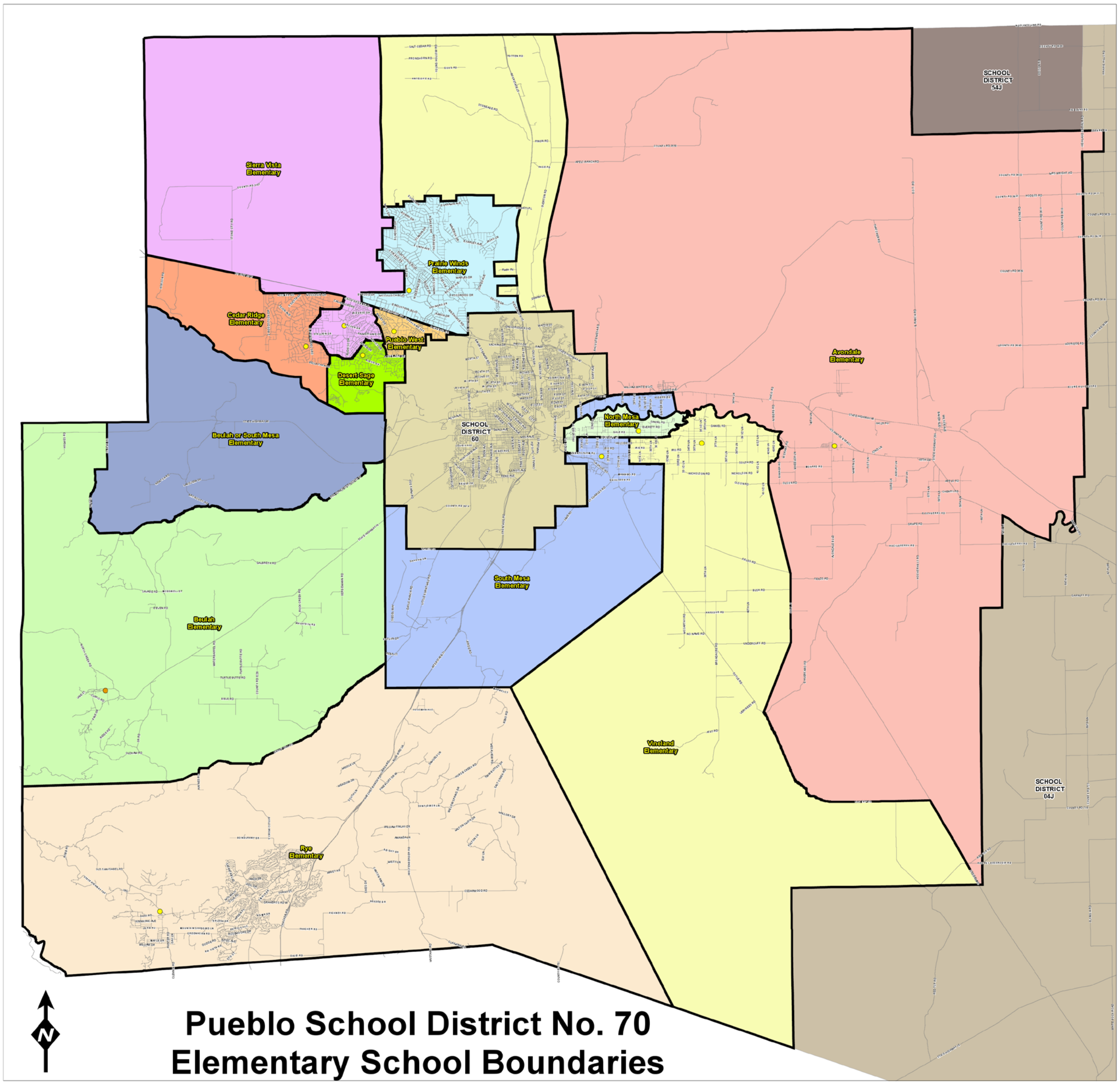
The feeder area approach of the mainstream District 70 schools was the most clear-cut to implement in the pattern matrices. If a zone was within the feeder area for a school, that cell of the pattern table received a positive number; otherwise the cell received zero. Zones that overlapped feeder area boundaries could have positive numbers for more than one mainstream school. In the elementary pattern table, District 70 zones also had at least two cells with positive numbers, since one would correspond to an elementary (K-5) school and another would correspond to a middle school. Smaller numbers were entered in the pattern table for District 70 zones going to alternative or charter schools.

For District 60, the study team thought there might be a preference for sending children to neighborhood schools. However, the district's International Magnet Schools might attract students from a broader area. In some cases the study team retained the numbers already present in the pattern tables. In other cases the study team subjectively assigned numbers of various levels reflecting their judgment of the likelihood of a child from that zone attending a particular school. **Table D-6** shows a sample of the elementary school trip pattern matrix to illustrate the different levels of values its cells may take.

Table D-6. Sample Section of the Elementary School Trip Pattern Matrix

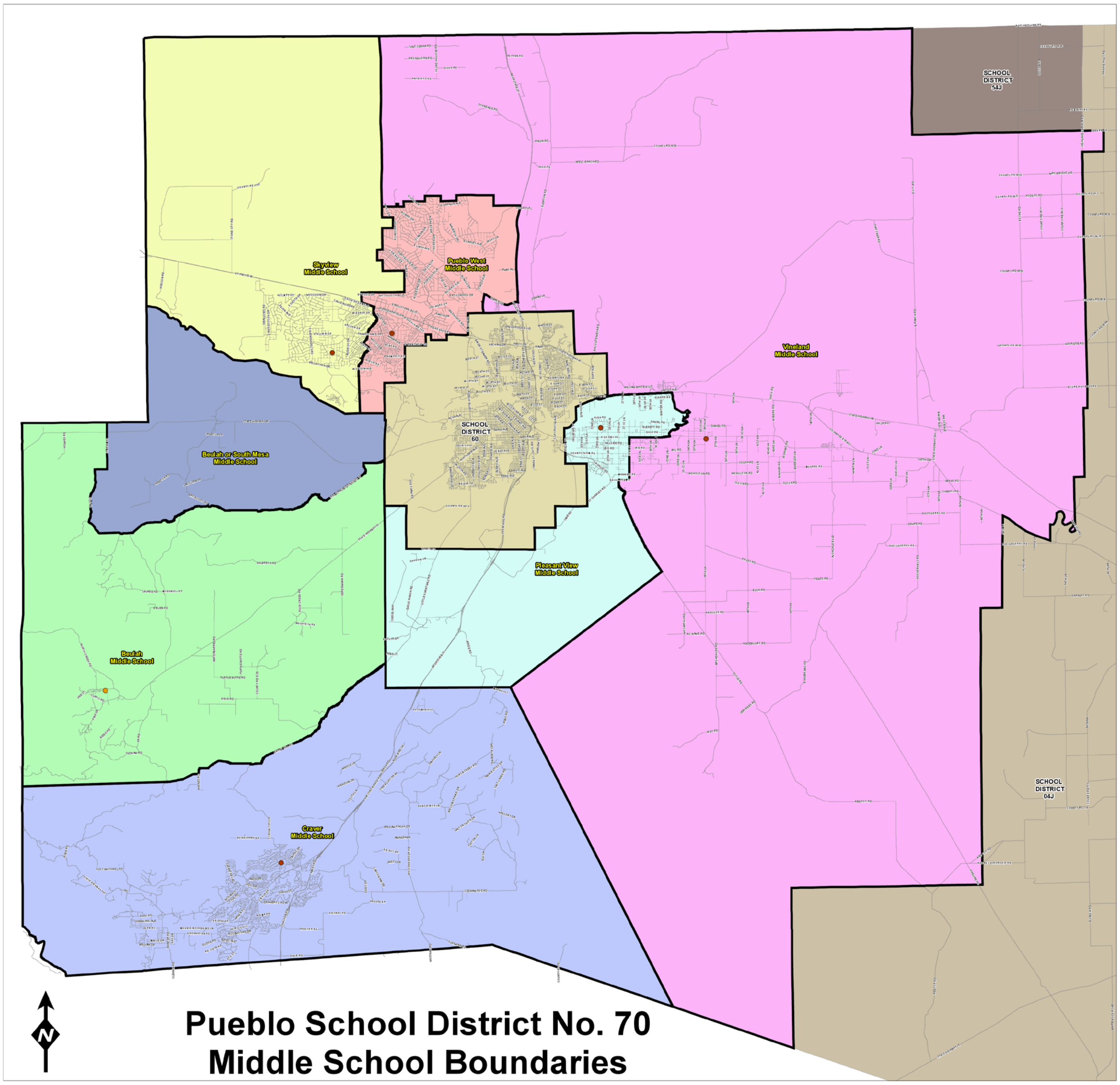
Zone	District 70 Connect Charter School (Zone 14)	Fountain International Magnet Elementary School (Zone 43)	Freed Middle School (Zone 50)	Irving Elementary School (Zone 77)
1	18	19	39	29
2	14	19	39	29
3	1	19	39	29
4	0	19	39	29
22	0	19	43	0
23	0	19	39	0
24	0	39	39	29

Note: Pattern matrix entries have no direct interpretation; they serve only as initial values from which the growth factoring process proceeds. The factoring process may increase or decrease the pattern table value.



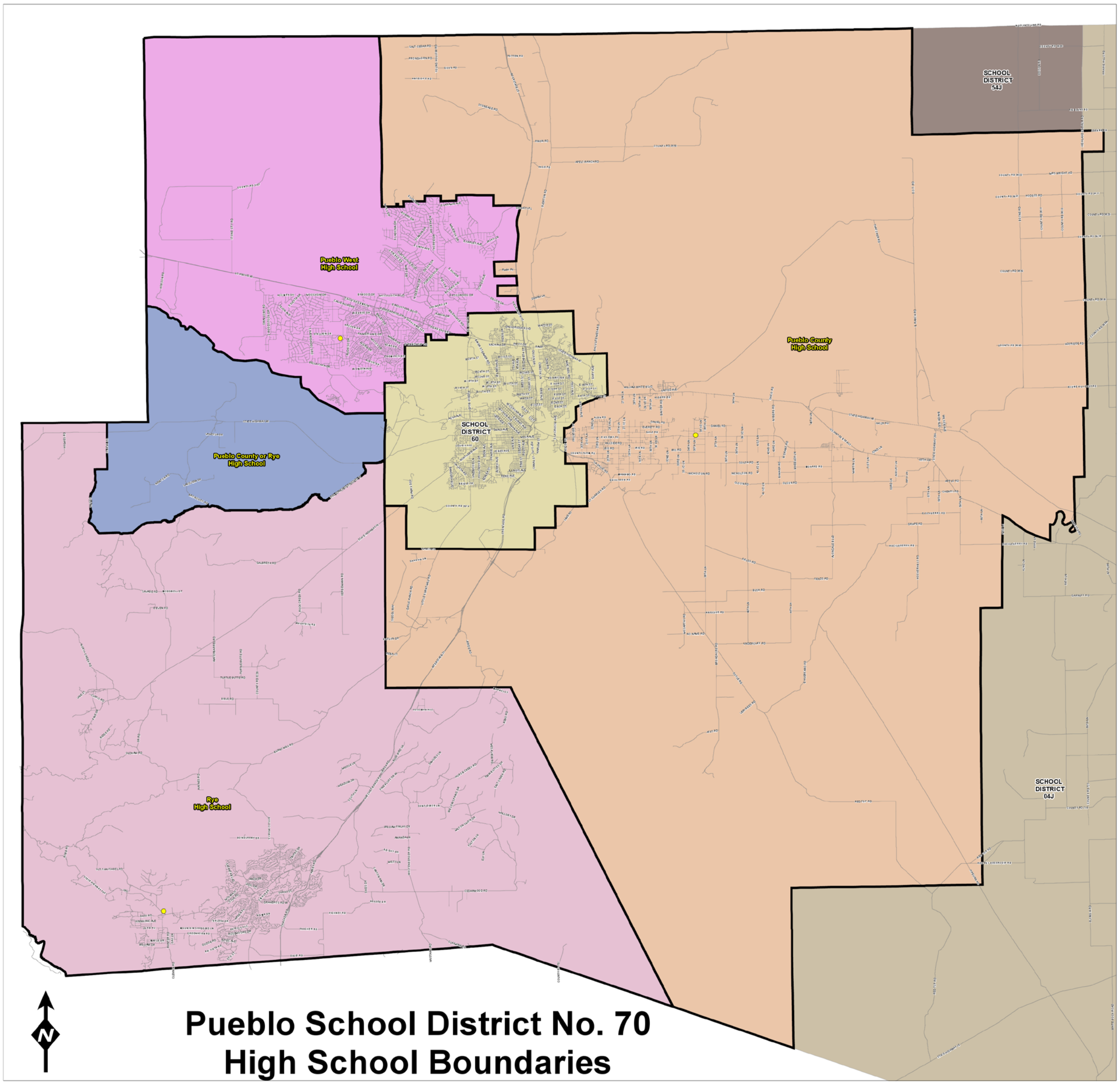
Source: Pueblo County School District 70

Figure D-2. District 70 Elementary School Enrollment Areas



Source: Pueblo County School District 70

Figure D-3. District 70 Middle School Enrollment Areas



Source: *Pueblo County School District 70*

Figure D-4. District 70 High School Enrollment Areas

D.6.3 How was the external-external trip pattern matrix changed?

After reviewing the external-external trip productions and attractions, PACOG made a comparison of the 1995 external-external trip pattern matrix and the resulting model output. PACOG decided to adjust the values of a few cells in the pattern matrix so that they would more closely match the relative values in the output matrix. **Table D-7** shows the final external-external vehicle trip pattern matrix.

Table D-7. External-External Vehicle Trip Pattern Matrix

		Destination Zone						
Origin Zone	Description	307	308	309	310	311	312	313
307	I-25 North	0	50	25	100	25	25	75
308	US 50 East	50	0	0	50	25	25	50
309	US 50 Business East	25	0	0	50	25	25	50
310	I-25 South	100	50	50	0	25	25	50
311	SH 78 West	25	25	25	25	0	10	10
312	SH 96 West	25	25	25	25	10	0	10
313	US 50 West	75	50	50	50	10	10	0

Sources: PACOG, 2010.

D.7 What changes affecting mode split were made?

Two changes were made to mode split processes, although neither would materially affect the model forecasts. The first change involved taking advantage of TransCAD's built-in functions and new batch scripting capabilities to speed up the school mode split calculations. The second change was to explicitly calculate the transit person-trips and high-occupancy vehicle (HOV) or carpool trips during mode split. Previously, only total auto vehicle-trips were calculated. Explicitly calculating transit and HOV trips allowed the study team to consider multimodal alternatives for the PEL Study.

The mode split percentages for home-based elementary school trips are based on the distance traveled, calculated as the straight-line distance between zone centers. The TransCAD script the study team received did this by:

1. Exporting the school trip tables to a database file with one record per cell. Because there are 313 zones in the PACOG model, this file has 97,969 records.
2. Using a linear approximation to calculate the straight-line distance based on the longitude and latitude of the zone centers, record by record.
3. Testing the distance of each record to see which range it fell within and applying the appropriate mode split factor.

Because the script made its calculations record by record, it required considerable execution time, about 30 minutes. The study team revised the script to use TransCAD's batch processing capabilities, which are optimized for handling large quantities of data very quickly. Using the batch capabilities, calculating zone-to-zone distances could be done in a single step. Likewise, applying the mode split percentages could be done in one step per distance range. The revised script takes only a minute or two to run.

The revised school mode split script also uses a built-in TransCAD function to calculate the great circle distance between two points, given their longitude and latitude, taking the earth's curvature into account.

To explicitly calculate transit person-trips and HOV trips required two other script routines. Because the existing script calculated highway person-trips from total person-trips, calculating transit person-trips is straightforward—they are the difference between the two. However, calculating HOV trips required additional assumptions. The existing PACOG model has calibrated values for vehicle occupancy by trip purpose, shown in the middle column of **Table D-8**. Vehicle occupancy or the average number of persons per vehicle can be calculated as follows:

Vehicle occupancy = 1 x Percent of single-occupant vehicles (SOVs)
+ 2 x Percent of two-person carpools
+ 3 x Percent of three-person carpools
+ 4 x Percent of four-person carpools
+ ….

Table D-8. Vehicle Occupancy and Carpool Percent of Trips by Purpose

Trip Purpose	Average Persons per Vehicle	Carpool Percent of Vehicle Trips
Low Income HBW	1.12	12%
Lower-Middle Income HBW	1.10	10%
Upper-Middle Income HBW	1.06	6%
High Income HBW	1.05	5%
Home-Based Elementary School	1.57	57%
Home-Based Secondary School	1.34	34%
Home-Based University	1.03	3%
Home-Based Shopping	1.34	34%
Home-Based Other	1.34	34%
NHB Work-Related	1.03	3%
NHB Other	1.33	33%

Sources: Barton-Aschman, 1990; JFSA, 2010.

The study team did not know the percentages of vehicles with two or more person carpools but expected them to be small for Pueblo County. Therefore, they made the assumption that all HOVs are two-person carpools; that is, the percent of three- or more-person carpools is zero. This simplifies the equation for vehicle occupancy to:

Vehicle occupancy = 1 x Percent of SOVs + 2 x Percent of HOVs
= 1 x (100% - Percent of HOVs) + 2 x Percent of HOVs
= 1 + Percent of HOVs

Therefore, the percent that HOVs represent of all vehicle-trips is one less than the vehicle occupancy. These percentages are shown in the third column of **Table D-8**.

D.8 What changes affecting assignment were made?

The study team made four changes affecting traffic assignment. Three of these changes involve how the roadway network is represented in TransCAD:

1. Juniper Rd. through Lake Pueblo State Park was added to the network as a toll road.
2. Delays and reduced capacities at the at-grade railroad crossings on Platteville Blvd. and 29th St. were modeled.
3. Capacity table values for lower functional class roads were reduced to reflect delays at signals or stop signs.

The fourth change was to the time-of-day factors for internal-external and external-external trips. Also, although they were not needed for traffic assignment, time-of-day factors were created for transit trips, analogous to those for auto trips.

D.8.1 How is Juniper Rd. modeled as a toll road?

Juniper Rd. through Lake Pueblo State Park connects McCulloch Blvd. in the southern part of Pueblo West to SH 96 west of Pueblo Blvd. Because it is within a state park, a fee is charged to drive on it and to use other state park facilities. However, many Pueblo West residents find it advantageous to buy an annual state park pass, whose fee was recently raised from $60 per year to $70, to gain unlimited access to Juniper Rd., which provides an alternative route to US 50.

The study team decided that Juniper Rd. should be included in the travel demand model and function as a toll road. The per-trip "toll" could be calculated by dividing the annual park pass fee by the number of times a Pueblo West resident was likely to use Juniper Rd. during the year.

However, the PACOG model considers only travel time in determining which routes are used during traffic assignment. To get the model to be sensitive to tolls, the study team used a common model "trick" of adding a short *dummy link* whose travel time was equivalent to the toll value. The toll value can be converted to an equivalent travel time by dividing by the *value of time*. The value of time is the amount a driver would be willing to pay to avoid a certain amount of congestion. The value of time varies by trip purpose, and national studies have estimated it to be about one-half the wage (or hourly earnings) rate for work trips and about one-quarter the wage rate for non-work trips.

The Census Bureau gives the median household income for Pueblo West as $53,279.06 in year 2005 dollars (the base year of the model). The average household size is 2.52 persons per household, so the median person in Pueblo West makes $21,142.48 per year or about $10.16 per hour. The study team believed most of the trips by Pueblo West residents through Lake Pueblo State Park were for work trips. Therefore, the value of time is half of $10.16 per hour or $5.08 per hour.

The number of trips made per year was varied to *calibrate* the model; that is, to give it the ability to duplicate current year conditions. The calibrated time value of the Juniper Rd. "toll" was determined to be 2.55 minutes.

Finally, the study team had to find a way to fix the travel time of the dummy link at 2.55 minutes. The PACOG model calculates free-flow travel time from a speed table based on area type (discussed previously in **Section D.6.1**) and the functional classification of the roadway, which will be discussed below. Together, the area type and functional class make up the speed class. The study team modified the TransCAD script to add a new speed class, 99, that indicates that TransCAD should not calculate free-flow travel time from the speed table, but instead use the number that was manually entered for that link.

During traffic assignment, TransCAD calculates the actual travel time from each road's free-flow time, the number of vehicles using the road, and the road's capacity. Because the time for the dummy link should stay constant at 2.55 minutes, it was given an artificially large capacity by coding it as being seven lanes in each direction—the same technique used for centroid connector links that represent the local roadway system in loading trips on to the network in TransCAD.

D.8.2 How are at-grade railroad crossings modeled?

At-grade railroad crossings were modeled using the same dummy link idea as for the Juniper Rd. toll. However, instead of coding these dummy links with a time representing the equivalent of a toll, their time is the average waiting time at the crossing. Also, the dummy link was coded with a reduced capacity to reflect capacity that cannot be used when a train is crossing and the warning gates are down. Just as they did for the free-flow time calculation, the study team added a new capacity class of 99 to indicate a manually-entered capacity value.

The study team consulted CDOT's *Colorado Rail Relocation Implementation Study* (2009) to better understand freight rail operations in the area. About 30 trains a day, or an average of 2.5 trains per hour, travel on the Burlington Northern Santa Fe (BNSF) tracks. Using typical locomotive and coal car lengths, the study team calculated that the warning gates would remain closed a little over 10 minutes per train crossing, or about 26 minutes of each hour. The capacity of the dummy rail crossing links was, therefore, reduced by 26/60 = 44 percent. The average waiting time was calculated assuming autos arrive uniformly within a given hour. **Table D-9** shows the resulting waiting time and link capacities.

Table D-9. Travel Time and Capacity for Railroad Crossing Links

Link Location	Average Waiting Time (min)	Peak-Hour Capacity (vehicles per lane)	22-hour Off-Peak Capacity (vehicles per lane)
Platteville Blvd. – Existing conditions	5.74	155	1,409
29th St. – Existing conditions	5.74	155	1,409
29th St. – With freight rail relocation	1.08	223	2,027

Sources: *JFSA; 2010; CDOT Colorado Rail Relocation Implementation Study, Jan. 2009; Burlington Northern Santa Fe Railway.*

Note: *The capacity of non-rail-crossing links for these streets is 275 vehicles during each peak hour and 2,500 vehicles during the 22-hour off-peak period.*

D.8.3 What changes were made to the capacity table?

When making initial model runs, the study team observed that the model was assigning too much traffic to arterial and local streets and not enough to I-25. Because arterial and local streets are affected by traffic signals and stop signs, their capacity should represent that involved in crossing an intersection rather than along a segment between intersections. For example, at a signalized intersection, the capacity is determined by both roadway characteristics and the ratio of green time to cycle length. For functional classes other than freeways and ramps, the study team reduced the per-lane capacity by anywhere from 40 to 55 percent. **Table D-10** shows the resulting capacity values.

Table D-10. Hourly Per-Lane Capacity by Functional Class and Area Type

Functional Class	10 CBD	20 CBD Fringe	30 Urban	40 Suburban	50 Rural
	Area Type				
1 Freeway*	1,600	1,700	1,900	1,900	1,900
2 Expressway	720	720	1,050	1,050	1,050
3 Major Arterial	250	250	360	360	450
4 Minor Arterial	225	225	275	275	400
5 Collector or Local	193	193	250	250	300
6 Ramp*	250	250	350	350	450
7 Centroid Connector	720	720	900	900	900

Sources: Barton-Aschman, 1990; JFSA, 2010.

*Notes: *Capacity values for freeways and ramps were not modified.*
Capacity class codes are determined by adding the area type code to the functional class code. For example, the capacity class code for a suburban major arterial is 40+3=43.

D.8.4 What are the time-of-day factors for the internal-external and external-external trip purposes?

The only trips using external station links are those for the internal-external and external-external trip purposes. This fact simplifies calibrating the common set of time-of-day factors for these two purposes. By comparing model forecasts to traffic counts, the study team adjusted the time-of-day factors to those shown in **Table D-11**. (Because the table is based on only the US 50 west, I-25 north, and SH 96 west external stations, it may not be suitable for the more regional modeling PACOG does. However, the same technique could be used to develop new time-of-day factors.)

Table D-11. New Internal-External and External-External Time-of-Day Factors

Trip Direction	AM Peak Hour	Off-Peak	PM Peak Hour	24-Hour Total
	Time Period			
Departing	3.6%	42.8%	4.1%	50.5%
Returning	3.1%	42.4%	4.1%	49.6%

Sources: CDOT, 2005-2009; JFSA, 2010.

Notes: Departing trips travel from production to attraction while returning trips travel from attraction to production. Internal-external trips are produced at external stations and attracted to internal zones. External-external trips are produced at and attracted to external stations.

D.8.5 What are the time-of-day factors for transit trips and how were they determined?

During an early model run, the same time-of-day factors as are used for auto trips were used for transit trips. The study team noticed that the resulting forecast showed an unreasonably large number of bus riders during the off-peak period, considering the limited Pueblo Transit service hours. The time-of-day factors for the two peak hours needed to be increased and the off-peak factors decreased.

To estimate a time-of-day profile for transit trips, against which to calibrate, the study team determined that total transit riders could be calculated by multiplying the number of bus trips each hour by the average number of people on each bus. The number of bus trips each hour is available from Pueblo Transit schedules. The study team used professional judgment to estimate the number of people per bus during each hour of service.

Once a desired transit time-of-day profile was established, the study team adjusted the morning and evening peak hour time-of-day factors for all transit trip purposes based on the relationship between the earlier transit forecast and the desired profile. The off-peak time-of-day factor was determined as the remainder so that the factors summed to 100 percent over the whole day. The final transit time-of-day factors are shown in **Table D-12**. Note that there are no transit time-of-day factors for the truck, internal-external, and external-external trip purposes because these types of trips would not be able to use transit.

Table D-12. Transit Time-of-Day Factors

	Time Period			
Trip Purpose and Direction	AM Peak Hour	Off-Peak	PM Peak Hour	24-Hour Total
Home-Based Work (all incomes)				
Departing	6.38%	41.97%	1.65%	50.00%
Returning	0.28%	18.64%	31.08%	50.00%
Home-Based Elementary and Secondary School				
Departing	14.18%	35.82%	0.00%	50.00%
Returning	2.24%	39.16%	8.60%	50.00%
Home-Based University				
Departing	5.73%	39.05%	5.22%	50.00%
Returning	0.00%	41.21%	8.79%	50.00%
Home-Based Shopping				
Departing	1.19%	37.27%	11.54%	50.00%
Returning	0.55%	35.44%	14.01%	50.00%
Home-Based Other				
Departing	3.39%	36.99%	9.62%	50.00%
Returning	1.70%	36.21%	12.09%	50.00%
Non-Home-Based Work-Related				
Departing	0.78%	26.14%	23.08%	50.00%
Returning	2.66%	43.22%	4.12%	50.00%
Non-Home-Based Other				
Departing	1.10%	81.04%	17.86%	100.00%
Returning	0.00%	0.00%	0.00%	0.00%

Source: Barton-Aschman, 1990; JFSA, 2010.

Notes: Departing trips travel from production to attraction while returning trips travel from attraction to production.
Non-Home-Based Other trips do not have distinct production and attraction ends.

D.9 What future roadways were analyzed as part of local improvements?

The study team examined seven local roadway improvement projects:

1. The Pueblo Blvd. Extension north of US 50 to I-25 Exit 108 (Purcell Blvd.)
2. The Eagleridge Blvd. Extension west to the Pueblo Blvd. Extension
3. The West Pueblo Connector from Purcell Blvd. and Joe Martinez Blvd. to D St. and Santa Fe Ave.
4. Improvements to Platteville Blvd. from Purcell Blvd. east to I-25 Exit 104 (future Dillon/Eden split diamond interchange)
5. The Industrial Blvd. Extension east to Wildhorse Rd.
6. Spaulding Ave. Extensions to complete a single roadway from Purcell Blvd. to 11th St.
7. The Tuxedo Blvd. Extension north to US 50

Because the Pueblo Blvd. Extension and the Eagleridge Blvd. Extension were always modeled together, they will be discussed together in the next section.

D.9.1 Pueblo Blvd. Extension with Eagleridge Blvd. Extension

CDOT's *Eden Interchange / Pueblo Blvd. Feasibility Study* (1999) established a preferred alignment for extending Pueblo Blvd. north of US 50. The extension would require a realignment of Wildhorse Rd., which presently continues north of the US 50 and Pueblo Blvd. intersection. The preferred alignment also uses portions of the existing Purcell Blvd. alignment as it nears I-25.

The future-year (2035) network files the study team received already had a section of the Pueblo Blvd. Extension coded north of Platteville Blvd. to a new road extending west from an upgraded I-25 Exit 106 (Porter Draw). This section was retained with certain attributes recoded as necessary. The remaining links were digitized from the alignment in the feasibility study.

Consistent with the feasibility study, the Pueblo Blvd. Extension was coded as a four-lane rural expressway (capacity class code = 52), with free-flow times manually calculated from its design speed of 60 mph. Later traffic analysis revealed the need for a six-lane cross-section between Spaulding Ave. and the relocated Wildhorse Rd.

The proposed trumped interchange with I-25 was coded with rural ramps (speed and capacity class codes = 56). Ramps for the major movements—northbound Pueblo Blvd. Extension to I-25, and southbound I-25 to southbound Pueblo Blvd. Extension—have two lanes and the others have a single lane.

The Eagleridge Blvd. Extension was coded as a four-lane suburban major arterial (speed and capacity class codes = 43) also using the alignment from the feasibility study.

D.9.2 West Pueblo Connector

The West Pueblo Connector will be a major boulevard or parkway, similar to Denver's Speer Blvd. It will link Pueblo West at Purcell Blvd. to Downtown Pueblo and Santa Fe Ave. It consists of several parts, some of which currently exist. The sections of the West Pueblo Connector are:

- The Joe Martinez Blvd. Extension between Purcell Blvd. and Pueblo Blvd. (SH 45) through the Honor Farm Park
- 24th St. between Pueblo Blvd. and Tuxedo Blvd.
- Tuxedo Blvd. south of 24th St. to its existing terminus at 18th St.
- A downtown section using an alignment through the railroad yards, with spurs to 13th St., Midtown Cir., and 1st St. allowing for connections to I-25. Exit ramps will also connect with SH 96
- An extension of the existing D St. alignment to connect to Santa Fe Ave. at the I-25 northbound Ilex St. ramps

TransCAD coding for each of these segments is described below.

Joe Martinez Blvd. Extension

The Joe Martinez Blvd. Extension was coded as a four-lane suburban major arterial (capacity class code = 43) with a design speed of 45 mph. The alignment was taken from PACOG's Future Roadway Network GIS layer. Some action plans involved two-lane scenarios to test possible construction phasing of the Joe Martinez Blvd. Extension. The extension was also coded with a short dummy link to test a toll scenario. A 75-cent toll was assumed to be comparable with the per-mile rate charged on E-470 and the Northwest Parkway in the Denver metro area. The toll resulted in volumes roughly one-tenth those the extension would attract as a free road. Such a toll level was greater than that calibrated for Juniper Rd. The study team chose not to investigate the revenue-maximizing toll level.

24th St. improvements

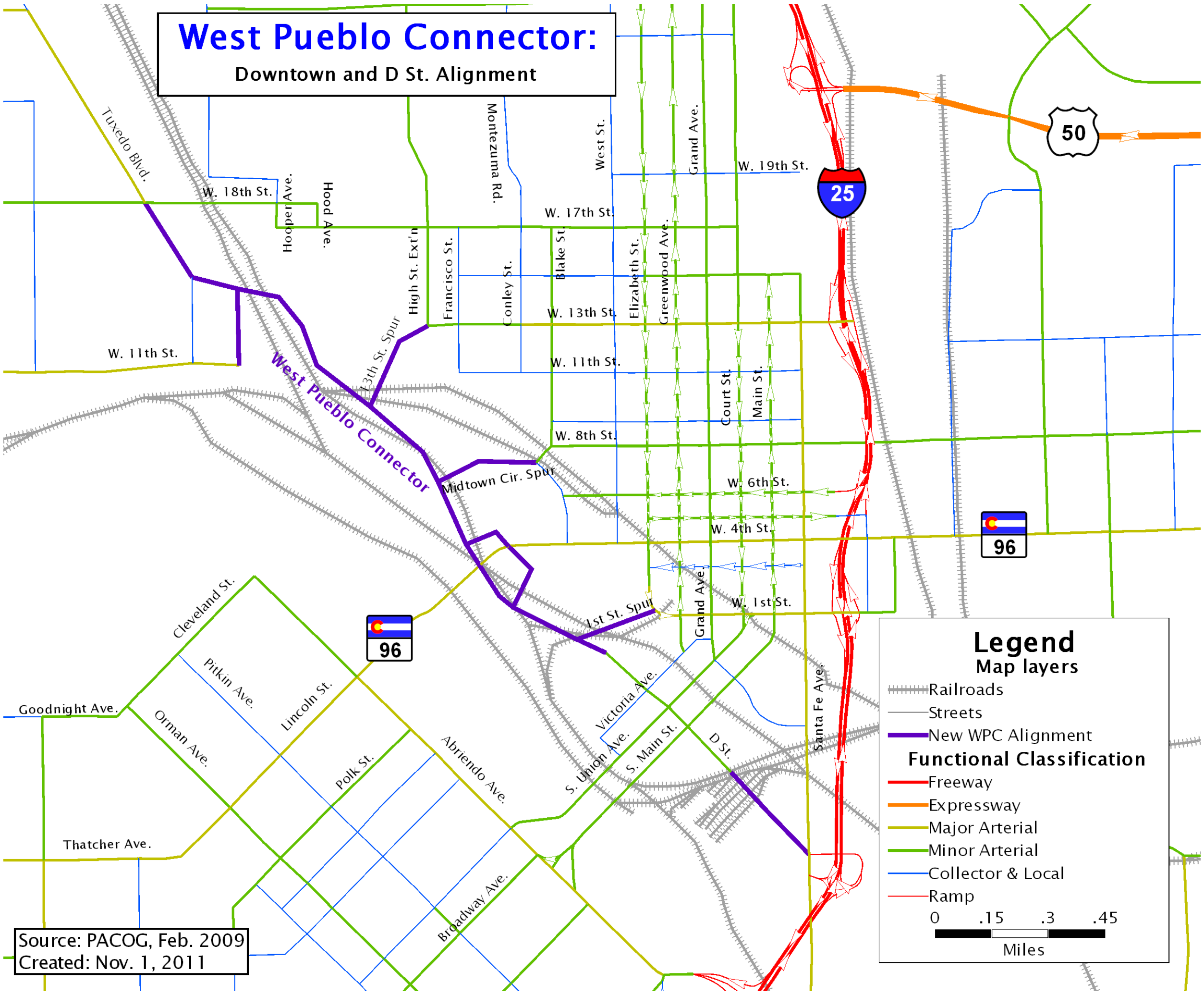
There are currently four-lane and two-lane segments of 24th St. between Pueblo Blvd. and Tuxedo Blvd. The existing roadway is an urban major arterial (speed and capacity class codes = 33). The two-lane segments were recoded to four lanes for scenarios where the West Pueblo Connector was present.

Tuxedo Blvd. improvements

Tuxedo Blvd. between 18th St. and 24th St. was coded as a two-lane urban major arterial in the networks the study team received from PACOG. The existing right-of-way (ROW) is sufficient for four lanes. This section of Tuxedo Blvd. was recoded as four-lane for scenarios where the West Pueblo Connector was present.

Downtown section and D St. improvements

From 18th St. and Tuxedo Blvd., the West Pueblo Connector heads southeast along the railroad yard. The alignment was digitized from a map in the PACOG 2035 *Long Range Transportation Plan* and is shown in **Figure D-5**. The thick purple lines in the figure indicate new facilities that would be constructed.



Note: WPC = West Pueblo Connector

Figure D-5. Alignment of West Pueblo Connector

At the west end, the West Pueblo Connector was coded as a four-lane urban major arterial (speed and capacity class codes = 33) between 18th St. and the spur south to 11th St. The spur south to 11th St. was coded as a two-lane urban major arterial. From the 11th St. spur to the 1st St. spur, the West Pueblo Connector was coded as a four-lane CBD Fringe major arterial (speed and capacity class codes = 23). The spurs east to 13th St. and Midtown Cir. are coded as four lane CBD Fringe minor arterials (speed and capacity class codes = 24). The ramps between the West Pueblo Connector and SH 96 are one lane in each direction, and have speed and capacity class codes of 26.

Although labeled as a spur, the connection to 1st St. is effectively a southern branch of the West Pueblo Connector. The 1st St. spur was coded as a two-lane CBD fringe major arterial. South of this spur, the portion of the West Pueblo Connector incorporating D St. is coded as a two-lane CBD fringe minor arterial. D St. was not in the network the study team received, so it was added with the same coding.

D.9.3 Platteville Blvd. improvements

Platteville Blvd. runs parallel to US 50 about 2 miles north. It is currently a two-lane minor arterial passing through rural and suburban areas (speed and capacity class codes = 54 and 44, respectively). As mentioned in **Section D.8.2**, Platteville Blvd. crosses the BNSF railroad tracks at grade. Just east of the railroad tracks, it changes name to Dillon Dr. There are plans to build a four-lane extension of Platteville Blvd. due east and west between here and the current I-25 Eden Interchange (Exit 104). This extension was included in the 2035 No Action network.

The Technical Advisory Team proposed several improvements to Platteville Blvd.:

- Upgrading it to a major arterial between Purcell Blvd. and I-25
- Building a grade separation at the BNSF Railway
- Widening it to four lanes between Purcell Blvd. and Dillon Dr.
- Widening it to six lanes between Dillon Dr. and I-25

The upgrade to a major arterial was modeled by changing the speed and capacity class codes to 53 and 43, retaining the existing area types (rural or suburban). The grade separation was modeled by removing the dummy link for the at-grade crossing and closing up the gap.

D.9.4 Industrial Blvd. Extension

Industrial Blvd. currently ends a little more than 1 mile east of Purcell Blvd. The Pueblo West Metropolitan District proposed connecting it to Wildhorse Rd. by building a bridge over Williams Creek. The Industrial Blvd. Extension was coded as a two-lane suburban collector or local road, with speed and capacity class codes of 45.

D.9.5 Spaulding Ave. Extensions

Several disjoint sections of Spaulding Ave. exist today. In Pueblo West, it makes a loop west of Main McCulloch Blvd. then goes east to about 0.5 mile east of Purcell Blvd. Another segment goes east from Pueblo Blvd., curves south by the YMCA, and then ends at the intersection with 31st St. Another section was created between 18th St. and 22nd St. by renaming one of the north-south streets in the Hyde Park neighborhood. The 2035 PACOG *Long Range Transportation Plan* shows an alignment that connects these three sections and extends south to 11th St.

Honor Farm Section

Spaulding Ave. between Purcell Blvd. and Pueblo Blvd. was coded as a four-lane suburban minor arterial (speed and capacity class codes = 44). This coding is consistent with the two-lane section west of Purcell Blvd.

West Pueblo section

The networks the study team received represent Spaulding Ave. by the YMCA as a four-lane suburban minor arterial. The Hyde Park segment between 18th St. and 22nd St. was not included in those networks. The study team digitized Spaulding Ave. south of 31st St. and coded it as a four-lane *urban* minor arterial (speed and capacity class codes = 34) to reflect development patterns in Hyde Park.

D.9.6 Tuxedo Blvd. Extension

The City of Pueblo provided plans to extend Tuxedo Blvd. north to a right-in, right-out only intersection with US 50 eastbound, just west of the BNSF railroad crossing. The study team digitized this roadway from existing network links at the intersection of Lowell Ave. and 29th St. Tuxedo Blvd. was coded as a two-lane suburban collector or local road (speed and capacity class codes = 45). Parker Blvd., another two-lane suburban collector or local road, was extended east to intersect with the Tuxedo Blvd. Extension about 0.10 mile south of US 50.

D.10 How were forecasts adjusted after the model run and why?

The study team conducted calibration runs of the PACOG travel demand model and made the adjustments described above to better match observed traffic counts. Of course, no model can match counts perfectly. National Cooperative Highway Research Program Report 255 (NCHRP 255, published in 1982) describes a procedure that allows the analyst to adjust model forecasts using calibration and count data for more reliable results. The procedure is based on the idea that the difference between counts and calibration output can be used for an additive or a multiplicative adjustment to future year forecasts. There are certain situations where one adjustment is preferred over the other.

The adjustments for a particular roadway segment are calculated as follows. First, let:

Count = the observed traffic count

CalibVol = the forecast from the (current year) calibration model run

RawForcast = the forecast directly from the future year model run

The additive adjustment to the forecast is applied as follows:

$$AddForcast = RawForecast - CalibVol + Count$$

The calibration forecast is also used to calculate a ratio,

$$Ratio = \begin{cases} \dfrac{Count}{CalibVol}, & if\ CalibVol > 0 \\ M, & if\ CalibVol = 0 \end{cases}$$

where *M* is a sufficiently large number. *Ratio* is then used for the multiplicative adjustment to the forecast:

$$MultForecast = Ratio \times RawForecast$$

The final adjusted forecast, *AdjForecast*, is then taken as:

$$AdjForecast = \begin{cases} \dfrac{AddForecast + MultForecast}{2}, & if\ AddForecast \geq 0\ and\ Ratio < R \\ AddForecast, & if\ AddForecast \geq 0\ and\ Ratio \geq R \\ MultForecast, & if\ AddForecast < 0 \end{cases}$$

where R is a threshold such that $1 < R < M$. (Note that *AddForecast* < 0 implies *Ratio* < 1.)The final adjusted forecast addresses the case where the additive adjustment would produce a meaningless negative volume, as well as the case where the calibration forecast is so much smaller than the count to cause the multiplicative adjustment to result in a huge increase to the raw forecast value. The study team used $R = 2$ for link volumes and $R = 3.5$ when applying the adjustment procedure to intersection turning movement volumes.

D.11 Where are the travel demand forecasts found?

Travel demand forecasts are found in several places in this PEL report:

- 2035 No Action turning movements are shown in intersection schematic diagrams in **Chapter 1, Section 1.4.3**.
- Future US 50 volumes with and without local improvement projects are shown in **Table 1-2** of **Chapter 1, Section 1.8**.
- The most detail forecasted volumes for US 50 and other roads are given in **Appendix B**, **Section B.2**, **Level 2 Purpose and Need Screening**.

D.12 What aspects of traffic operation does Synchro forecast?

Synchro forecasts delay and LOS at signalized and unsignalized intersections using methods from the *Highway Capacity Manual*. It requires more detailed roadway geometry information than TransCAD. For example, Synchro is sensitive to lane widths, the presence and length of turning bays, and how lanes are allocated to different turning movements at intersections. Synchro can also represent a wide variety of signal timing programs including fixed intervals, semi-actuated operation, and coordinated actuated operation. Synchro is also able to model the flashing left arrow signals along US 50 in the City of Pueblo.

D.13 Who provided the Synchro networks?

CDOT Region 2 Traffic provided Synchro networks for the five currently signalized intersections in all but the westernmost end of the US 50 Corridor. CDOT provided both morning and evening peak hour networks.

The study team digitized simple networks for the currently unsignalized intersections at Swallows Rd. and West McCulloch Blvd.

Representations of future year intersection and interchange configurations were based on conceptual roadway designs adhering to AASHTO and CDOT design standards.

D.14 How does VISSIM model traffic operations?

VISSIM uses a technique called *traffic microsimulation* to model traffic operations. Microsimulation simply means that VISSIM considers cars individually rather than in groups as some other simulators do, or by aggregate relations the way TransCAD does. VISSIM tracks the movement of vehicles through time intervals of as little as one-tenth of a second. VISSIM requires certain inputs regarding driver behavior, such as the distribution of speeds that drivers would most like to travel at. It has model components reflecting how closely one car will follow another and when a car will change lanes. Because cars are individually tracked, VISSIM can produce even more detailed forecasts than Synchro.

D.15 What aspects of traffic operation is VISSIM better at forecasting than Synchro?

VISSIM is able to model sections of roads between intersections, which Synchro doesn't do. This is an important capability should the analyst wish to study merging behavior, for example. VISSIM is also better at modeling closely-spaced intersections that function as a single unit, such as a continuous flow intersection, a diverging diamond interchange, or even the two ramps of a conventional diamond interchange. Synchro forecasts for short links must be reviewed with caution, because Synchro ignores situations when delays are so severe that queues at one signal back up the whole block to an earlier signal. Also, the *Highway Capacity Manual* relationships that are used in Synchro were calibrated based on relatively uncongested intersections, so Synchro's forecasts for heavily congested intersections are less reliable.

D.16 Where are the traffic operation forecasts found?

Traffic operations forecasts are found in many locations throughout this PEL report, including:

- **Chapter 1, Section 1.4.3** illustrates current year intersection, approach, and movement LOS.
- **Chapter 1, Section 1.4.3** shows 2035 No Action intersection, approach, and movement LOS.
- **Table 2-4** of **Chapter 2, Section 2.9.2** presents LOS for alternative intersection configurations.
- **Table 2-9** of **Chapter 2, Section 2.14.3** shows Corridor-wide travel times forecasted by VISSIM.
- **Table 3-2** of **Chapter 3, Section 3.2.1** shows average Corridor-wide delay—also forecasted by VISSIM—for the No Action Alternative and the Preferred Alternative.
- **Table 3-3** of **Chapter 3, Section 3.2.1** presents Corridor-wide travel times by peak hour and direction for the No Action Alternative and the Preferred Alternative.

- **Appendix B, Section B.2, Level 2 Purpose and Need Screening**, has intersection LOS for US 50 and selected intersections off US 50, such as along Pueblo Blvd. (SH 45).
- **Appendix B, Section B.4, Level 4 Comparative Analysis of Alternatives,** has details for all six alternatives that were considered, including Corridor-wide travel times, segment travel times, Corridor-wide delay, mainline segment LOS, and intersection LOS.

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