INTERSECTION TYPE AND DENSITY STUDY: TRAVEL MODEL APPLICATIONS AND DEVELOPMENT PATTERN INSIGHTS

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Abstract

The paper presents results of a study of the geographic distribution of intersections by type in the metropolitan Denver region, and use of the data in the Integrated Regional Model (IRM), a next-generation travel model being built by the Denver Regional Council of Governments. The paper presents: a description of the methods used to categorize complex intersections, and to account for inconsistent basemap coding practices; depiction of the results of the work, including geographic intersection distribution; and presentation of the use of intersection type in the IRM (for example, its effects on the use of transit and walk modes in the region). The paper will also present other applications of the data, including discussion of the development policy sensitivity supported by the model through the inclusion of this variable (for example, TOD effects, different approaches to urban design such as neo-traditional design, typical suburban design, etc.)

Context of the Analysis

Identification of the extent to which different development patterns, and different areas of the region, are supportive of bicycling and walking is a key element of the Denver Regional Council of Governments (DRCOG) regional planning responsibilities. DRCOG is in the latter stages of a project to develop a disaggregate, activity-based travel model for the Denver region. This model will implement some of the latest advances in travel demand forecasting, and when complete, will be one of approximately six such models being used for regional planning in the United States today (with perhaps that many again in the rest of the world.) Key technical features of the model under development include:

- Execution of models at the unique, individual household/person level. This is in contrast to existing aggregate models, which operate on groups of households that are assumed to be identical to one another for modeling purposes.
- Prediction of each person's daily activity pattern, with sensitivity variables that permit this pattern to be tailored to the individual's personal and household characteristics, and to change in response to changes in congestion and other conditions. This is in contrast to existing models, which have a few household characteristics, but few or no person characteristics to influence travel behavior, and also are largely insensitive to congestion and other transportation system service conditions.
- Production of personal travel in "tours" (excursions from the household that make one or more stops, and then return home again), rather than in separate, disconnected "trips" (simple travel from one place to the next), as is the case with existing models.
- Location of stops in each tour at the xy-point level, rather than at the traffic analysis zone (TAZ) polygon level.

Readers wishing more information on such models and their growing use in regional planning should consult Vovsha, Bradley & Bowan (2004.) As part of the design process for this new model, an extensive visioning exercise was undertaken, aimed at identifying key planning and policy decision that the new model must support. Decisions of particular relevance to the analysis presented in this paper include:

- How much funding should be allocated to the development of rapid transit facilities?
- How much funding should be allocated to the development of bicycle and pedestrian facilities?
- To what extent should municipalities take steps to foster the development of urban centers and other forms of transit-oriented development?

To answer these questions effectively, DRCOG needed a practical method of assigning a level of bicycle and pedestrian "friendliness", based on design characteristics of the area in question. Obviously, bicycle/pedestrian friendliness is a key driver of whether or not people will choose to use those modes of travel. However, bicycle/pedestrian friendliness also is a key driver of transit use. If people know, for example, that they can accomplish errands without a car in the vicinity of their workplace, then their willingness to ride transit to work increases.

A variety of design characteristics seem intuitively relevant to a bicycle/pedestrian friendliness evaluation: examples might include sidewalk characteristics (width, connectivity, etc.), presence of bicycle trails or lanes, street width and traffic, among other characteristics. However, data is not easily acquired on most of these characteristics, particularly the sidewalk characteristics that seem particularly relevant. DRCOG therefore began evaluating more easily obtainable information that could be used as "surrogate" variables: characteristics of the development pattern that, while not directly productive of pedestrian friendliness, were nevertheless closely associated with it. As density of intersections by type has been used with some success in this role in other model development projects, DRCOG undertook an analysis of the region's intersections for two separate years. A basemap from TeleAtlas was used for our 2005 data, and a basemap from our partners at the Regional Transportation District (RTD), the metro Denver's regional transit authority, for the 1999 data.

It is important to emphasize that the real determination of an area's pedestrian friendliness is whether or not the urban design of that area actually is associated with a greater propensity for people in that area to walk or bicycle, in comparison to another area with perhaps less pedestrian-friendly design characteristics. As it developed its regional travel model, DRCOG therefore tested the use of the intersection density/type variables in its development of econometric models that predict behaviors such as travel mode choice. These tests and outcomes are described in the following sections.

Analytical Approach and Process

Once the business need had been identified, DRCOG set about creating region wide intersection data. Two years have been compiled so far, 1999 and 2005. The 1999 data came from a base map created locally through Pierson Graphics and paid for by DRCOG and RTD (RTD 1999): this dataset is commonly referred to as the "RTD" base map, and covers the pre-2007 DRCOG 9 county region. The 2005 data is from Tele Atlas which produces its data by County, therefore involving the merging of 9 separate datasets (Tele Atlas North America, 2005.) The geographical area used is the pre-2007 DRCOG 9 county region (before the inclusion of southwest Weld County), which includes the Colorado Counties of Adams, Arapahoe, Boulder, Broomfield, Clear Creek, Denver, Douglas, Gilpin, and Jefferson. The intersections were derived from street centerline data; however, the street centerline data was organized differently, and from different sources for the two different years. This created issues unique to each of the datasets. In the end, DRCOG was able to tally overall intersections by numerous types of geographies, as well as comparing the geographical distribution of intersections by the three major types, 3 way intersections, 4 way intersections, and cul-de-sacs. The data produced has now been used in DRCOG's new activity-based model, as will be described in later sections of this paper.

As the intersections involved with some classes of roads to not contribute to pedestrian friendliness, the first step in network data analysis was to query the following classes out: ramps, turn lanes, and freeways. As the Tele Atlas 2005 street centerline data has Feature Class Codes (FCC) for all links, it was easy to eliminate Freeways (FCC=A1x) and Ramps & Turning Lanes (FCC=A6x). The RTD 1999 data had a street type field that indentified freeways and ramps, and some links had to be tagged for removal by hand.

Once the freeways and ramps were removed, intersection point files were created from the linear street networks. The process was the same for both years. The street centerline file was converted from shapefile to coverage. Then a build was performed on the coverage to create nodes as well as the pre-existing arcs. The relationship between the nodes and arcs was the key for identifying intersection types. Each arc had a direction, Begin ID, and End ID. For any intersection, the Begin ID leaving an intersection, another arc's End ID entering that same intersection, and the node point for that intersection were the same number. From this ID match, we were able to combine the Begin and End IDs' into one column, and get a unique count of each number. If there were 4 total Begin and End IDs' associated with one intersection, we knew that that particular intersection was a four way. The table with the count by Begin and End ID was then linked to the Nodes by the Node ID. Ultimately, the vast majority of nodes had a value of one (cul-de-sacs), three (3 way intersections), or four (4 way intersections). Those that had a value of 2 were thrown out, since the two arcs do not constitute an intersection. A small number of 5 way intersections were identified, but as there were not enough of them to be significant, they were combined with the 4 way intersections.

See Figures 1and 2

Several factors caused some noise in the data. One was the representation of a number of roads by two lines (one line for each direction). This caused overrepresentation of intersections. When a double line road crosses a normal single line road, there are two nodes for one intersection. When two double line roads cross each other, there are 4 nodes for that intersection. To account for this, all links part of double lined roads were tagged. In the Tele Atlas 2005 dataset, links with FCC codes of A25, A35, A45, and A48 were all part of double line roads. This permitted easy tagging of the 2005 dataset. In the RTD 1999 dataset, there was no attribute to identify double line roads, but they were small enough in number to easily tag by hand: links that were part of double line roads were tagged with a factor of 2, while all other roads had a factor of 1. From the ID match between links (or arcs) and nodes discussed previously, we were able to sum these factors for each nodes. Using this system, nodes where a double line crosses a single line having a factored sum of 6, and nodes where two double lines cross having a factored sum of 8. To get a proper total count of intersections by type, the number of "6 factor" intersections was divided in half, while the number of "8 factor" intersections was divided by four. The vast majority of misrepresented intersections fell into these two categories. Ultimately, DRCOG created an adjustment factor field in which normal intersections were given a factor of 1, “6 factor” intersections 0.5, and “8 factor” intersections 0.25.

See Figure 3

Another factor that caused noise in the data is unique to the Tele Atlas 2005 dataset, because Tele Atlas packages its data by county. This introduces a problem for cases in which intersections sit on County boundaries. The Link Begin and End IDs’, and the Node IDs’ are only unique to the county they are in, making it impossible to simply merge the counties together. An intersection along a county boundary that appears to be a three way intersection is often is shown to be a four way intersection when both counties are displayed. There are a few situations in the Denver region in which a major road runs along a County boundary, causing this error to occur in numerous locations. Similarly, a road that is exiting a county may appear to be a cul-de-sac, when display of both counties’ data shows that there is in fact no intersection there. To correct for this problem, all intersections along county boundaries have 1 added to their intersection sum. Three way intersections become four way intersections (as they should be), and Cul-de-sacs are removed from the dataset since there is no such thing as a two way intersection. This solution is not perfect, but the small number of places where this fix would be wrong is insignificant, and the alternative is a hand fix of every intersection along County boundaries, which would be very time consuming. For regional totals these intersections need to be divided by two since they appear in two counties. Ultimately, these intersections were given a value of 0.5 in the adjustment factor field.

See Figure 4

Development Patterns Revealed by the Data

Summarizing the cleaned datasets produced several interesting results. Perhaps the biggest surprise was that the number of cul-de-sacs in the region is larger than the number of “traditional” four way intersections. The fact that three way intersections made up a considerable majority was also surprising. These numbers are quite consistent between 1999 and 2005, with four-ways making up about 20% of total intersections, cul-de-sacs 23 to 24%, and three-ways 56 to 57%. When looking at the data on a county-by-county basis, the data was also quite consistent from 1999 to 2005. In 8 of 9 DRCOG region counties (Adams, Arapahoe, Boulder, Broomfield, Clear Creek, Douglas, Gilpin, Jefferson), three way intersections dominated, cul-de-sacs were second most frequent, and four-ways were the smallest number. These eight counties are primarily suburban or rural. The only county that was different was Denver, which is mostly urban. In both years Denver had a slight majority of four way intersections, three-ways were a close second, and cul-de-sacs were a much smaller third. The total number of intersections in the region increased 15% between 1999 and 2005, from 78,816 to 90,580. Four way intersections actually had the greatest increase in that time period, about 21%, while cul-de-sacs increased by 18% and three-ways by 12%. Figure 5 at the back of the paper presents intersection summaries by region and county.
See Figure 5

Geographical analysis of each intersection type provides an interesting snapshot of the history of urban design. For this analysis, four way intersections, three way intersections, and cul-de-sacs were divided into separate point shapefiles. Using spatial analysis, density grids were created for each of the three intersection types for both 1999 and 2005. When looking at the area where four way intersections are the most dense (50 intersections per square mile and up), there is an almost perfect correlation between that area and the 1920 Urban footprint of the Denver Metro area. This strongly suggests that all pre-1920 development was strictly on a grid pattern. The densest areas of both the three way intersections and cul-de-sacs form a ring around the four way intersection densities, which is to be expected, as three ways and cul-de-sacs are more characteristic of suburban areas. The three way intersections appear to be fairly dense in all suburban areas, while cul-de-sacs are most dense in specific suburban neighborhoods. When high density cul-de-sac areas (30 intersections per square mile and up) are overlaid with the 1960 urban footprint, the areas of high densities of cul-de-sacs fall right around the edges of the 1960 footprint. This suggests that suburban type developments with subdivisions including cul-de-sacs probably did not start until approximately 1955. High densities of three way intersections (50 intersections per square mile and up) fill in the areas between the cul-de-sac and four way intersection high densities. The densities for both 1999 and 2005 intersections follow the patterns mentioned in this paragraph, and there are no significant differences between the two concerning spatial location of the most dense areas.

See Figures 6 and 7
** also see Figures 8 and 9 for more geographical analysis not discussed in the paper*

There are some basic trends that can be derived by all this data. The older urban area has more four way intersections, while the suburban areas have more three way intersections and cul-de-sacs. As far as Urban Design goes, the data suggests that pre-World War II development was primarily on a traditional grid pattern, while post World War II development switched to curving streets in subdivisions that had primarily three way intersections and cul-de-sacs. However, the data also suggests that there may be a trend to start going back to a more traditional design, hence four way intersections having the highest percentage of growth between 1999 and 2005.

Activity Model Application and Results

DRCOG used the intersection type/density data in the context of developing choice models for its new modeling system: these models typically are referred to by travel modeling practitioners as discrete choice or logit models. The models estimate the probability that a person will select each of the choices that s/he is facing. For example, if a person can get to work by driving alone, by carpooling, by riding a bus, or by taking a train, a logit model is a common method of estimating the probability that a given person will take any of these options. Such models show the dependence of these options' probability on characteristics of the options themselves, and on characteristics of the person. For example, household income is a well-known driver of mode choice: higher income households are generally less likely to take transit, while lower income households are more likely. For purpose of this discussion, it is helpful to examine the multinomial logit equation, which can be expressed as follows:

$$P_i = \frac{e^{V_i}}{\sum_{j=1}^{J} e^{V_j}}$$

This equation shows the probability that alternative 'I' (i=1,2,3,…,J) will be selected from a set of J alternatives. The terms V_j are referred to as "utility functions", which may be thought of for this discussion as desirability scores for the alternatives. They typically are expressed as:

$$V_j = B_o + B_1 * X_1 + B_2 * X_2 + \ldots + B_n * X_n$$

Where:
B_n are constants that are calculated during the statistical "estimation" of the model.
X_n are person or option characteristics that the modeler believes influence the person's choice of option.

When developing a travel model, the modeler starts with a hypothesis that certain characteristics influence choice, then goes through the statistical analysis to see if that hypothesis is true. In general, a finding that the B in the above equation for a given characteristic is significantly different from zero means that the characteristic is indeed influential in the choice of option. For readers who wish further information on logit modeling, there are a number of complete treatments of this topic (see Koppelman and Bhat, 2006, or Ben-Akiva and Lerman, 1985.)

The goal, then, of DRCOG's development of an intersection type/density variable, as described in this paper, was to test whether or not it influenced peoples' travel choices, by including it in logit models, and determining whether its B_n was significantly different from zero (that is, that it contributed to the desirability score) Such tests were run, and the intersection type/density variable did indeed prove to be significant in two classes of models:

- **Tour mode choice models**. These are models that predict a person's choice of primary mode for a "tour" (defined as departure from home, followed by a sequence of stops, followed by return home) for a variety of tour purposes (work, shopping, school, etc.) For example, a person may make a tour to the downtown area via transit. Figure 10 shows the results of the work tour model estimation (Cambridge Systematics, 2007.) Note that the intersection type/density variable appears in the walk and walk-to-transit modes on both ends of trip, and on destination end for drive-to-transit, and is significantly different from zero in all these cases.
- **Trip mode choice models**. These are models that predict a person's choice of mode for each "trip" in a tour (where a "trip" is simply the movement from one stop to the next.) Figure 11 shows the results of the trip mode choice model estimation (Cambridge Systematics, 2008.) Note that the intersection type/density variable appears in the

desirability score for the same options as the work tour mode choice model, and also in the bicycle score.

See Figures 10 and 11

Conclusions

Several conclusions can be drawn from the work here presented. The first two relate to the original motivation for this research:

- It proved to be practical to use commercially available roadway base map products to calculate how the density and type of intersection varies across the region; and
- The type/density calculated in this way did help to predict peoples' propensity to walk, to bicycle, and to walk to transit. That is, the type/density does seem to be an effective surrogate variable for bicycle and pedestrian friendliness.

The additional conclusion that can be drawn from this work is that maps of the type/density statistic are useful in helping planners understand the evolution and pattern of different development types in a metropolitan region. Such maps proved to be very useful in quickly enhancing planners' and policy makers' understanding of their region.

References

Ben-Akiva, Moshe, and Steven Lerman, "Discrete Choice Analysis: Theory and Applications to Travel Demand", MIT Press, 1985.

Cambridge Systematics, Inc., "Tour Mode Choice Model Documentation", DRCOG Integrated Regional Model Project Files, 2007.

Cambridge Systematics, Inc., "Trip Mode Choice Model Documentation", DRCOG Integrated Regional Model Project Files, 2008.

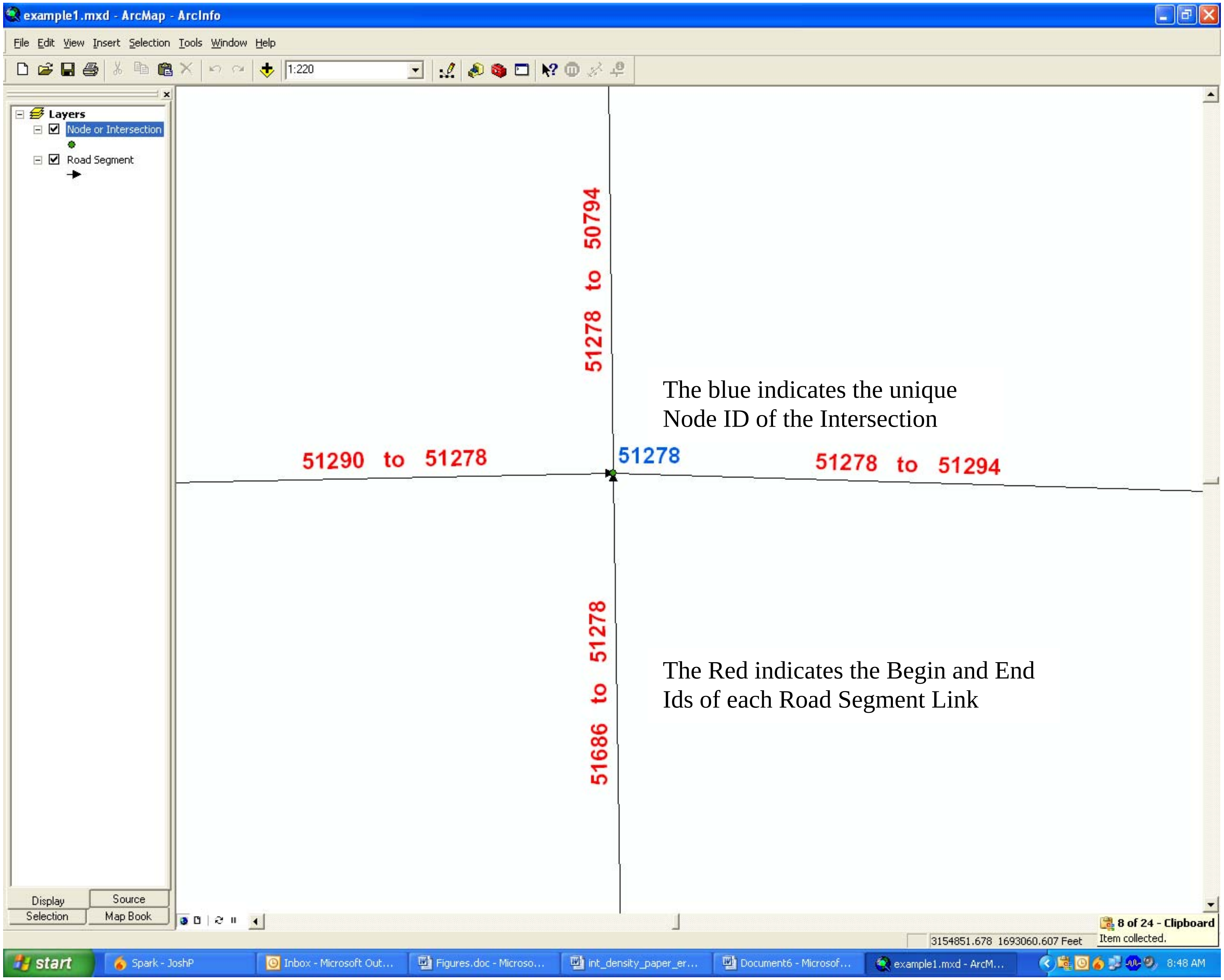
Koppelman, Frank, and C. Bhat, "A Self Instructing Course in Mode Choice Modeling: Multinomial and Nested Logit Models", U.S. Department of Transportation, Federal Transit Administration, 2006

Vovsha, Peter, Mark Bradley, and John Bowman, "Activity-based travel forecasting models in the United States: Progress since 1995 and Prospects for the Future," Presented at the EIRASS Conference on Progress in Activity-Based Analysis, 2004, Maastricht, The Netherlands. Web link: http://jbowman.net/papers/VBB04.pdf (2008.)

Regional Transportation District, "Denver Regional Street Basemap", 1999

Tele Atlas North America, "Street Centerline datasets from Adams, Arapahoe, Boulder, Broomfield, Clear Creek, Denver, Douglas, Gilpin, and Jefferson Counties", 2005

Figure 1



example1.mxd - ArcMap - ArcInfo
File Edit View Insert Selection Tools Window Help
1:220
Layers
Node or Intersection
Road Segment
51278 to 50794
51290 to 51278
51278
51278 to 51294
51686 to 51278
The blue indicates the unique Node ID of the Intersection
The Red indicates the Begin and End Ids of each Road Segment Link
Display
Source
Selection
Map Book
8 of 24 - Clipboard
Item collected.
3154851.678 1693060.607 Feet
start
8:48 AM

Figure 2

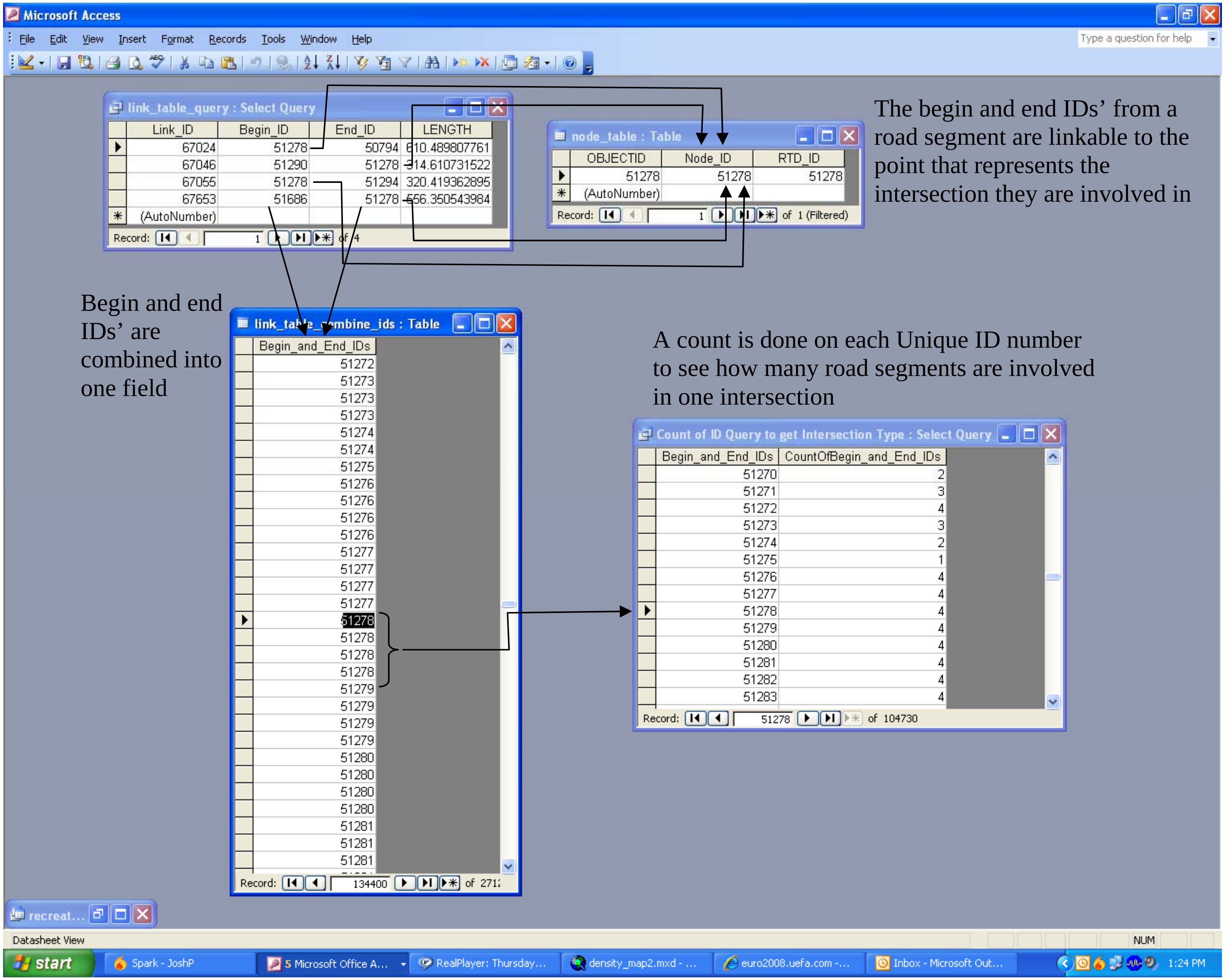

Microsoft Access
link_table_query : Select Query
node_table : Table
The begin and end IDs' from a road segment are linkable to the point that represents the intersection they are involved in
Begin and end IDs' are combined into one field
link_table_combine_ids : Table
A count is done on each Unique ID number to see how many road segments are involved in one intersection
Count of ID Query to get Intersection Type : Select Query

Figure 3

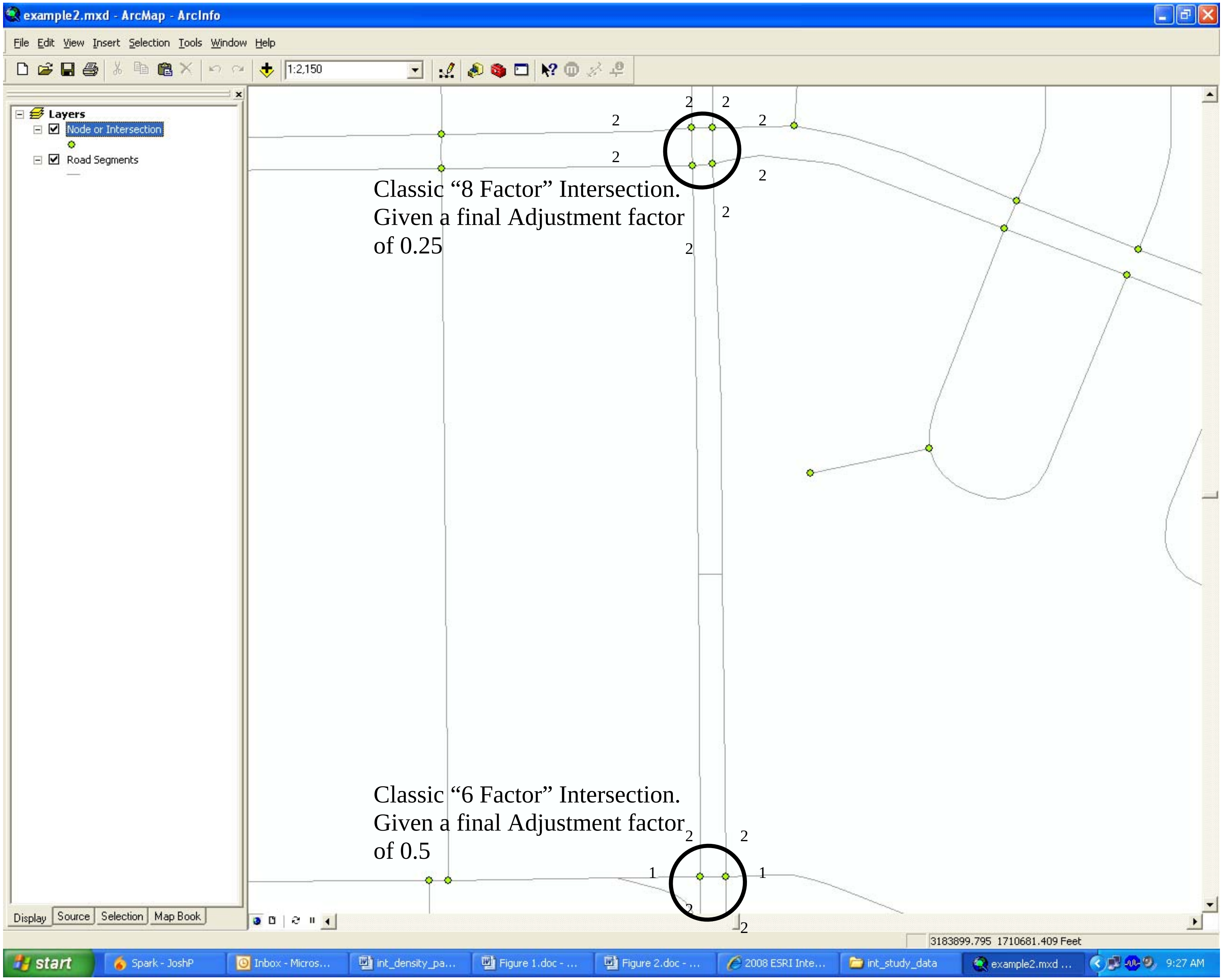

example2.mxd - ArcMap - ArcInfo
File Edit View Insert Selection Tools Window Help
1:2,150
Layers
Node or Intersection
Road Segments
Classic "8 Factor" Intersection. Given a final Adjustment factor of 0.25
Classic "6 Factor" Intersection. Given a final Adjustment factor of 0.5
Display Source Selection Map Book
3183899.795 1710681.409 Feet
start
9:27 AM

Figure 4

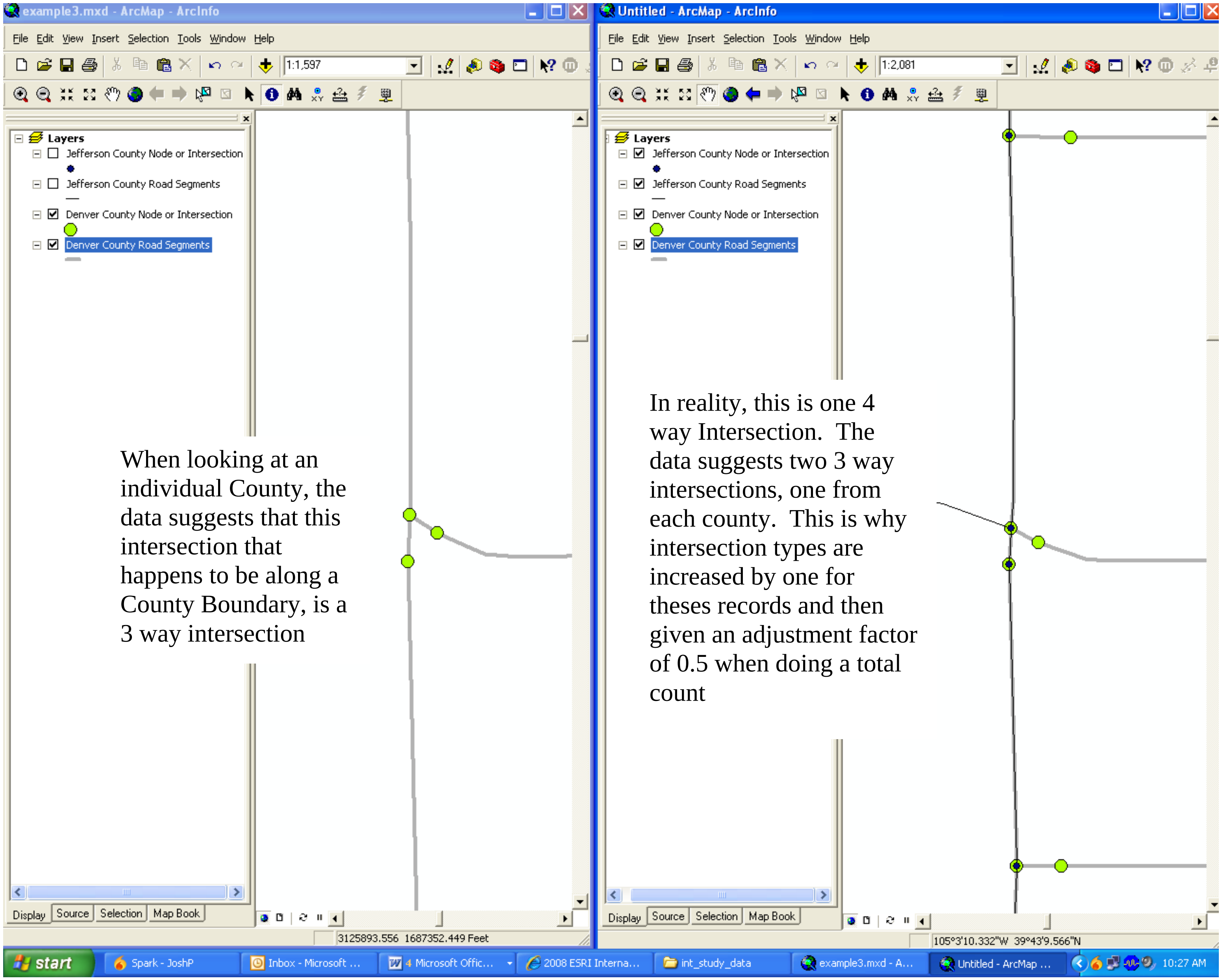

example3.mxd - ArcMap - ArcInfo
Untitled - ArcMap - ArcInfo
Layers
Jefferson County Node or Intersection
Jefferson County Road Segments
Denver County Node or Intersection
Denver County Road Segments
When looking at an individual County, the data suggests that this intersection that happens to be along a County Boundary, is a 3 way intersection
In reality, this is one 4 way Intersection. The data suggests two 3 way intersections, one from each county. This is why intersection types are increased by one for theses records and then given an adjustment factor of 0.5 when doing a total count
3125893.556 1687352.449 Feet
105°3'10.332"W 39°43'9.566"N

Figure 5: Intersection Summaries

Intersections by Type, DRCOG 9 County Regional Totals, 1999 and 2005

Intersection Type	1999 Totals		2005 Totals		1999-2005 Changes Num Increase	Pct Increase
Cul-de-sacs	18,440	23.40%	21,688	23.94%	3,248	17.61%
3 ways	45,251	57.41%	50,655	55.92%	5,404	11.94%
4 ways	15,125	19.19%	18,237	20.13%	3,112	20.58%
Total	78,816		90,580		11,764	14.93%

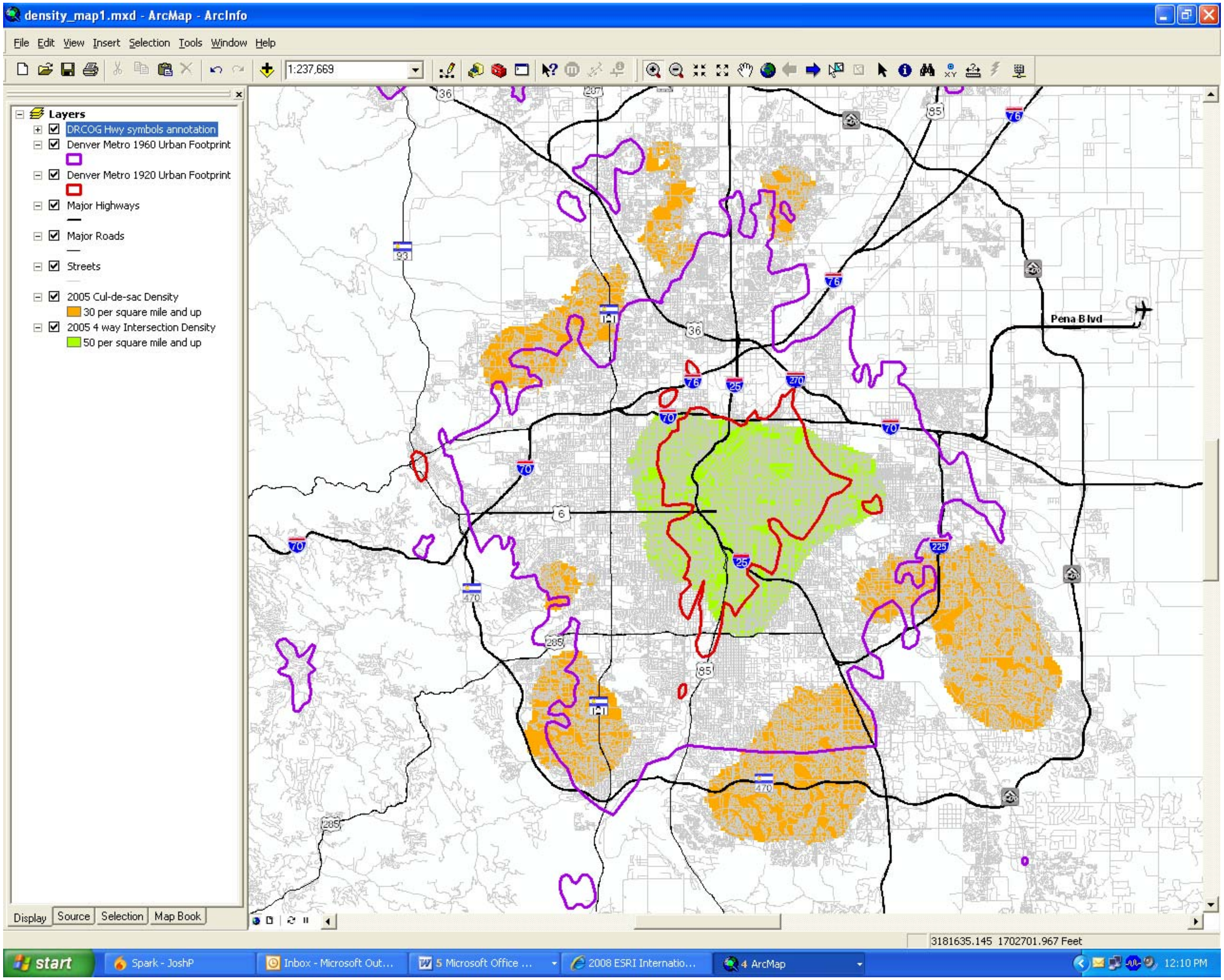
Intersections by County, 1999

County	Cul-de-sacs	3 ways	4 ways
Adams	2,185	6,598	1,926
Arapahoe	3,616	8,305	2,397
Boulder	2,468	5,431	1,615
Broomfield	331	719	209
Clear Creek	644	1,017	182
Denver	828	5,387	5,536
Douglas	2,939	5,154	810
Gilpin	372	634	53
Jefferson	4723	11,453	2,293

Intersections by County, 2005

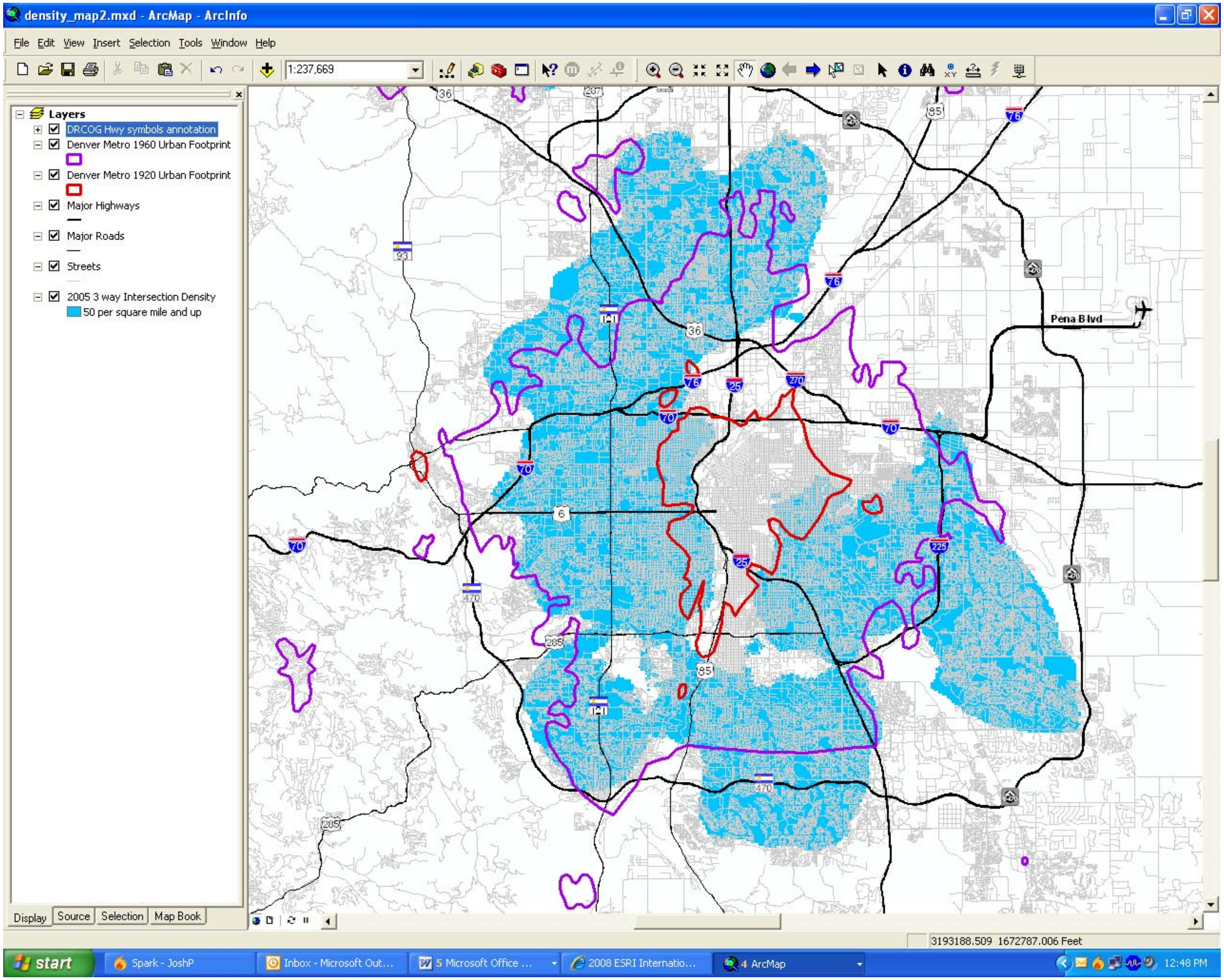
County	Cul-de-sacs	3 ways	4 ways
Adams	2,632	7,698	2,560
Arapahoe	4,498	9,956	3,278
Boulder	2,897	6,156	1,836
Broomfield	468	1,011	331
Clear Creek	522	937	205
Denver	1,113	5,832	6,066
Douglas	3,719	6,331	1,173
Gilpin	312	616	66
Jefferson	5,489	12,105	2,943

Figure 6 – Correlation between high density of 4 way intersections and the 1920 Denver Urban footprint, and correlation between high density of cul-de-sacs and the 1960 Denver Urban footprint



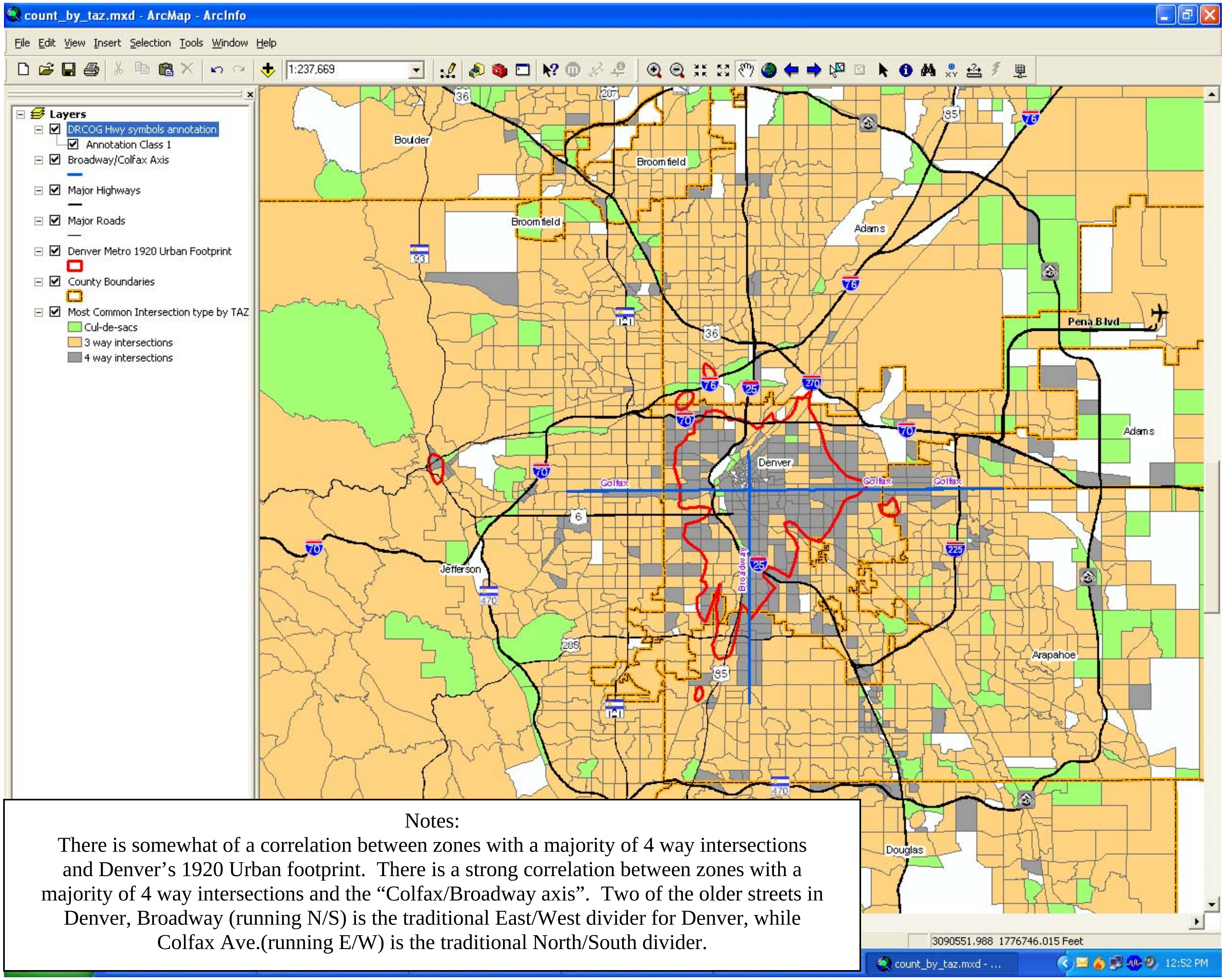
Sources: Urban Footprints and Intersection Type Densities: DRCOG; all roads and streets: Tele Atlas

Figure 7 – High density of 3 way intersections



Sources: Urban Footprints and 3 Way Intersection Density: DRCOG; all roads and streets: Tele Atlas

Figure 8 – Intersections summarized by DRCOG's Transportation Analysis Zones (TAZ).
The Zones are color coded according to which intersection type is the majority in that zone

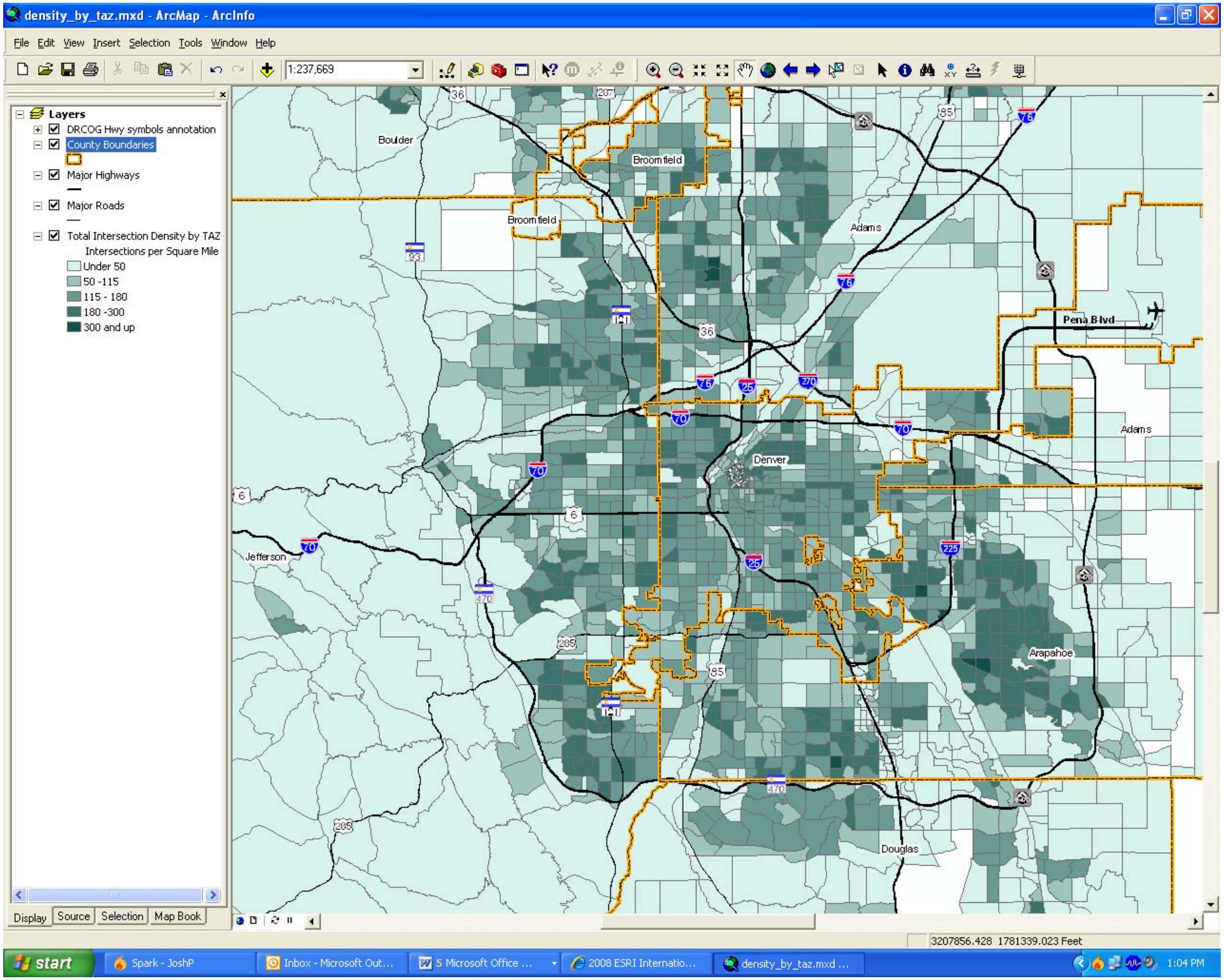


Notes:

There is somewhat of a correlation between zones with a majority of 4 way intersections and Denver's 1920 Urban footprint. There is a strong correlation between zones with a majority of 4 way intersections and the "Colfax/Broadway axis". Two of the older streets in Denver, Broadway (running N/S) is the traditional East/West divider for Denver, while Colfax Ave.(running E/W) is the traditional North/South divider.

Sources: Urban Footprints, TAZ and County Boundaries, Summaries by TAZ's: DRCOG; all roads and streets: Tele Atlas

Figure 9 – Density of Intersections by Transportation Analysis Zone (TAZ)



Sources: TAZ and County Boundaries, Densities by TAZ's: DRCOG; all roads and streets: Tele Atlas

Figure 10: Home based work tour mode choice model

	Coeff	T-stat
Cost($)- Low Income	-0.251	-4.0
Cost($)- Medium Income	-0.119	-3.7
Cost($)- High Income	-0.084	-1.3
Cost($)- Missing income	-0.018	-0.2
In-vehicle time (min)	-0.020	constr
Transit walk time (min)	-0.050	-10.8
Transit first wait time (min,<=10)	-0.050	-10.8
Transit other wait time (min)	-0.030	constr
Walk mode time (min)	-0.050	-10.8
Bike mode time (min)	-0.071	-6.3
Drive access time/total IVT	-1.431	-4.5
Local bus time/total transit IVT	-0.680	-5.2
SR2-constant	-2.902	-28.0
SR3-constant	-3.424	-28.0
BK-constant	-3.400	-5.1
WK-constant	-6.032	-8.1
WT-constant	-3.935	-5.3
DT-constant	-4.672	-6.1
DA,SR- Arrive at dest. in AM peak	-0.995	-4.0
DA,SR- Leave from dest. in PM peak	-0.265	-1.3
DA- Shopping stops/tours remaining	0.845	5.6
SR-No car in HH	5.040	4.6
SR-HH cars >0, <workers	1.365	7.0
SR-HH cars>=workers, <adults	0.552	3.7
SR-low income	0.167	1.1
SR-high income	-0.046	-0.3
SR-missing income	-0.104	-0.4
SR-female	0.571	6.2
SR-Escort stops/tours remaining	5.390	26.5
SR-Other stops/tours remaining	0.494	8.5
SR2-1 person HH	-1.660	-7.0
SR3-1 person HH	-2.454	-6.8
SR3-2 person HH	-1.706	-9.3

Figure 10 (continued): Home based work tour mode choice model

	Coeff	T-stat
WT-No car in HH	12.160	8.8
WT-HH cars >0, <workers	5.098	10.5
WT-HH cars>=workers, <adults	2.369	6.2
WT-low income	0.325	1.0
WT-high income	-1.713	-3.0
WT-missing income	-0.630	-1.1
WT-origin intersection density	6.812	2.6
WT,DT-destination intersection density	11.330	3.8
WT,DT-destination retail density	0.251	4.0
DT-No car in HH	9.215	5.9
DT-HH cars >0, <workers	3.508	6.2
DT-HH cars>=workers, <adults	1.561	3.5
DT-high income	-1.180	-2.0
DT-missing income	-0.983	-1.4
DT-female	0.656	3.3
BK,WK-No car in HH	9.790	7.1
BK,WK-HH cars >0, <workers	3.071	5.1
BK,WK-HH cars>=workers, <adults	1.545	2.7
BK,WK-low income	0.370	0.8
BK,WK-high income	-1.502	-1.9
BK,WK-missing income	0.580	0.8
WK-age over 50	-0.791	-1.7
WK-female	-0.759	-1.8
BK-female	-2.157	-4.0
WK-Origin,destination mixed use density	0.738	2.9
WK-Origin,destination intersection density	8.538	3.2
BK-Origin,destination retail density	0.183	2.5
BK-Origin,destination intersection density	6.450	1.9
Nesting parameter	0.555	11.5
Observations	5266	
Final log-likelihood	-3931.1	
Rho-squared(0)	0.578	
Rho-squared(const)	0.360	

Key to options names (Characteristics with no option name appear in all options):
DA = drive alone
SR = shared ride
SR2 = shared ride, two persons in car
SR3 = shared
WT = walk to transit
DT = drive to transit
BK = bicycle
WK = walk

Figure 11: Trip mode choice mode

	Coeff	T-stat
Generalized Time	-0.0132	-25.6
DT – Constant	0.489	2.1
DT – HH cars >0, <drivers	-0.142	-0.6
DT – Missing Income	1.69	2.0
DT – High Income	0.450	1.7
WT – Constant	-0.734	-4.6
WT– HH cars >0, <workers	0.740	5.7
SR3 – constant	3.40	24.8
SR3 – 1 person HH	-1.19	-7.1
SR3 – 2 person HH	-0.928	-10.9
SR2 – 1 person HH	-0.962	-8.9
SR2 – constant	0.358	2.9
SR – No car in HH	-0.601	-4.6
SR – High Income	-0.0481	-0.9
SR – Missing Income	-0.271	-2.0
SR – Household Members age 5-15	-0.269	-14.0
SR – Household nonworking adults	0.126	3.8
SR – Work Tour	-0.889	-15.2
SR – School Tour	-0.513	-6.1
SR – Escort Tour	1.29	5.4
SR – Shop Tour	1.68	14.1
SR – Meal Tour	1.50	10.1
SR – Social/Recreation Tour	0.888	9.2
DA – constant	1.32	15.0
DA – HH cars >0, <drivers	-0.429	-7.3
DA – Low Income	-0.247	-2.5
DA – Low-med Income	-0.178	-2.8
DA – Missing Income	-0.656	-4.4
B – Constant	-1.29	-4.9
B – Male	0.863	3.5
B – Work Based tour	-0.739	-2.1
B – Origin intersection density	5.39	1.8
W – Age under 35	0.623	6.4
W – Origin intersection density	3.30	3.4
W – Destination intersection density	0.729	6.5
W – Work Tour	-0.603	-5.8
W – School Tour	1.01	8.2

Figure 11 (continued): Trip mode choice model

	Coeff	**T-stat**
Transit – Origin Intersection Density	1.31	1.1
Transit – Destination Mixed Density	0.443	3.3
All – Same as tour mode	1.40	15.0
All – same as tour mode – only outbound trip	1.53	18.8
All – same as tour mode – only return trip	1.60	18.9
All – same as tour mode – first outbound trip	0.273	2.7
All – same as tour mode – first return trip	0.105	1.3
All – same as tour mode – last outbound trip	0.231	2.4
All – same as tour mode – last return trip	0.127	1.5
SB – WT Tour	-3.84	-7.4
SR3 – DT Tour	-6.50	-19.5
SR3 – WT Tour	-5.26	-26.6
SR3 – SB Tour	-1.10	-7.3
SR2 – WT Tour	-1.38	-8.1
SR2 – SB Tour	1.44	7.6
SR2 – SR3 Tour	1.52	10.2
DA – DT Tour	-1.49	-8.5
DA – WT Tour	-3.59	-19.2
DA – SR3 Tour	0.764	6.2
B – WT Tour	-4.22	-6.9
B – SR3 Tour	-2.30	-5.5
B – SR2 Tour	-3.16	-8.1
B – DA Tour	-3.30	-7.9
SR – escort to work trip / am peak period	-2.10	-13.1
SR – work to escort trip / pm peak period	-1.45	-9.6
SR – home to escort trip / am peak period	2.36	14.6
SR – home to escort trip / midday period	1.32	3.8
SR – home to escort trip / pm peak period	0.747	1.4
SR – home to escort trip / evening period	-0.663	-1.0
SR – escort to home trip / midday period	0.268	1.0
SR – escort to home trip / pm peak period	1.67	9.4
SR – escort to home trip / evening period	-1.25	-1.6

Key to option names: same as Figure 10.