Multiscale Design for *The National Map* of the United States: Road Thinning for Topographic Mapping

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ABSTRACT: This paper reports on progress in generalization and selective feature removal for a subset of fundamental base map layers that enables competent mapping through scales ranging from 1:24,000 to 1:1,000,000. Thinning and partitioning methods are applied to road features and labels for *The National Map* of the United States. Roads are thinned adaptively, which removes features by feature hierarchy and network connectivity, yet preserves characteristic urban/rural local density patterns that can be lost through simple category removals. The paper demonstrates thinning for label hierarchies within road categories, improved preference in placement for more important road labels, and selective removal of labels through scale. Use of the Radical Law to guide matches between thinning parameters and suitable scales of representation is also shown. Inspection of graphic results of these treatments can help to establish parameters that suit automated base map design for United States topographic mapping.

KEYWORDS: Map design, generalization, topographic mapping, road thinning, road labeling

Introduction

Cartographic generalization employs a variety of operations to reduce map content and detail in a manner that legibly portrays desired features and conditions at a reduced map scale. Recent road generalization work within the scale range of 1:24,000 (24K) to 1:1,000,000 (1M) indicates that midrange scales (such as 1:100,000 to 1:300,000) are particularly difficult to represent through common display-based strategies, which eliminate road categories and use simpler, thinner line symbols for road representations (Brewer and Buttenfield, 2010). This paper describes current efforts to improve road elimination and generalization when producing high-quality cartographic displays for multiscale topographic maps distributed through *The National Map* of the United States.

The "Thin Road Network" tool is a relatively new generalization tool offered by Environmental Systems Research Institute, Inc. (Esri) (Punt and Watkins, 2010; Briat et al., 2011; ArcGIS Resources, 2012a). It calculates all possible itineraries through a road network, and uses the frequency of all itineraries in which a road segment participates to set a binary visibility flag for relative road segment importance. Less important roads are thus removed from the display (but not from the database). Through trial and error, a user sets a thinning distance—a 'minimum itinerary length'—that suits the scale of mapping to clear away short, tangled and coalescing line segments, while retaining major thoroughfares for smaller scale representations from detailed roads data. Esri offers guidelines for setting itinerary lengths for specific mapping scales in its documentation, but these guidelines do not account for local variations in road density, as in a study area with urban, suburban, and rural regions.

Using the Thin Road Network tool with a single minimum itinerary length tends to homogenize road network density at smaller scales. Analogous to previous generalization results with hydrography (e.g., Buttenfield et al., 2011; Stanislawski, 2009), this research tests the use of partitions for retaining differential road densities among areas in a map display. Through the hydrography research, pruning tools are being developed and distributed which enrich NHD flowlines (National Hydrography Dataset stream channels) with an upstream drainage area attribute (Stanislawski et al., 2007). The additional attribute provides a basis for pruning stream features to smaller-scale representation and for tapering stream symbols to improve map display. This paper applies a similar process to transportation data, working with minimum itinerary parameters in the Thin Road Network tool to enrich road data with visibility attributes which support scale change and improve symbol hierarchies. Also, the paper will demonstrate how road thinning attributes may be used to control the selection of road labels.

Fundamental to this work is a general goal of fully automated and database-driven multi-scale cartography; it is not an option for USGS cartographers to hand-select a few streets that run through the middle of each town to improve each of their maps, when the challenge is to map the whole country with limited staff and continued national database updates.

Sample Area

Figure 1a shows the full Atlanta, Georgia dataset used in this research covering sixty-one (61) 7.5-minute quadrangles (U.S. 1:24,000 topographic maps) with 393,920 road segments. This dataset has been partitioned into three stratified road density classes (Stanislawski et al., 2012). To explain and demonstrate cartographic thinning and partitioning, a small sub-area is selected (and shown by the rectangular sample outlined in orange) north of the city center that overlaps with other processed map data, such as Level of Detail generalized databases for hydrographic features, terrain shading and contours, land cover, labels for populated places, and emergency response structures. The sample area covers approximately six quadrangles and contains 55,261 road features and 6,043 kilometers (km) of roads. Figure 1a also shows three road density partitions calculated for the Atlanta region, which range through rural (in green), suburban (blue), to urban (purple). A sample area shown in Figure 1b, used for many examples in this paper, is outlined in red in Figure 1a and is inset from the edges of the rectangular sample to avoid edge effects. The sample area includes a sparser partition to the northwest and a denser partition in the south and east.

Figure 1: Sample area: a) area boundaries within the wider Atlanta dataset. Background colors show road density partitions, with purple (most dense), blue (intermediate), and green (most sparse)]; b) a detailed version of roads in the sample area, shown at 300K; and c) a detailed view of these TomTom roads shown at 24K. The location of the area shown in c is indicated with a dashed rectangle in b.

Figure 1c demonstrates road detail in the dataset that is used by the USGS for quadrangle maps at 24K. U.S. topographic maps utilize TomTom road data (previously Tele Atlas); and even this small portion in Figure 1c gives a visual sense that these data would be overly detailed for smaller scale representations. Esri thinning tools provide a systematic mechanism to retain roads that are thoroughfares, because they are part of longer itineraries, and to flag as invisible other roads that are less important to the network. Stoter et al. (2009) report on a similar need to attribute importance levels for roads and other feature types for automated topographic mapping.

Road segments are symbolized using a basic categorization based on road type (such as U.S. Route, State Route, local road, and ramp). Some U.S. road datasets include a secondary or collector road category, but this attribute is not up-to-date or available with sufficient completeness and accuracy for the entire U.S. to be useful for national mapping. That is to say, Road_Class, MTFCC_Code, and CFCC_Code fields are not consistently populated. It is possible to establish partial categorization of roads by querying alphanumeric characters in attribute fields for Interstate, U.S. Route, State Route, and County Route names. Doing so however leaves the majority of roads in a remainder class that can be treated as local and other roads (shown by light gray lines in Figure 1b). An ordering of basic road categories is used within the Esri thinning tool as an importance parameter, helping the tool select, for example, U.S. Routes over local roads with similar routing.

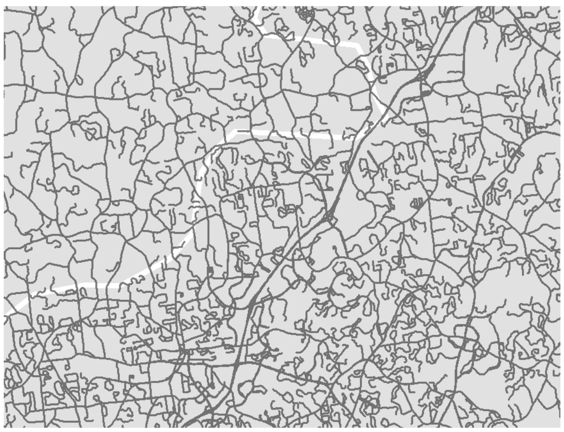
Road Thinning Through Scale

Figure 2 shows the sample area at 300K with five of eleven tested thinning levels. Figure 2a shows all roads in the sample area. Cartographers will frequently effect basic thinning by simply removing a category of less important roads, such as all local roads, but this solution leaves little content for intermediate scales. For example, 80 percent of the total road length is comprised of local roads for this sample area. That shortcoming in road hierarchy is the root of what this paper intends to address, namely, retaining major thoroughfares and rural collector roads without either losing all local roads, or having them coalesce in urban areas.

The full set of minimum itinerary lengths for thinning tests used for this research is 500m, 1,000m, 1,500m, 2,000m, 2,500m, 3,000m, 3,500m, 4,000m, 5,000m, 6,000m, 7,000m, and 14,000m. Fewer tests were performed at longer minimum itinerary lengths for the practical reason that longer itineraries take longer to compute (tens of hours on a desktop computer using ArcGIS version 10.1).

Figures 2b to 2f show testing results for selected thinning levels, based on minimum itinerary lengths, using the Esri tool. It is apparent that local variations in road density seen in the original data (Figure 2a) are progressively homogenized by application of the thinning tool when using a single minimum itinerary length parameter. Esri documentation recommends initiating thinning with a minimum itinerary length of 3,000m for non-gridded road patterns and 6,000m for regular gridded road patterns for a 300K display (ArcGIS Resources, 2012b). Visual inspection of the outcomes in Figure 2 indicates that itinerary lengths shorter than 3,000m display coalescence problems for shorter road segments, particularly in the portion of

a) All roads with no category or hierarchy distinctions.

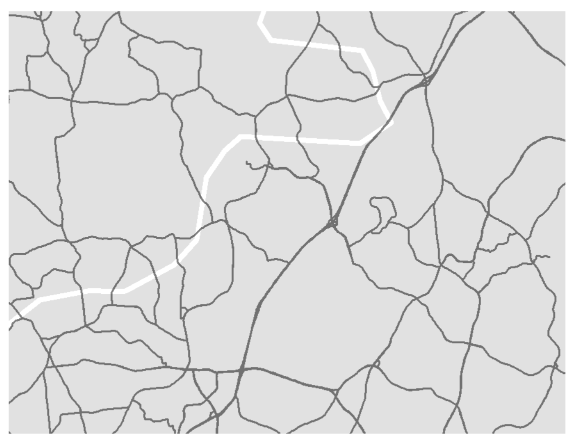


b) 500m

c) 1,500m

d) 3,000m

e) 6,000m



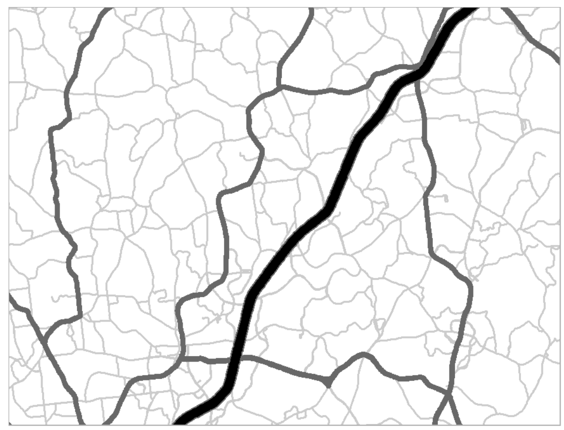
f) 14,000m

Figure 2: Sample roads with a) no thinning, and thinning to b) 500, c) 1,500, d) 3,000, e) 6,000, f) 14,000 meter minimum itinerary lengths. Each outcome was generated by thinning the original data in panel 2a, with the exception of the 14,000m solution, thinned incrementally from a 7,000m outcome (not shown). A white line provides a background indication of the location of the partition boundary, marking overall density differences in the two partitions.

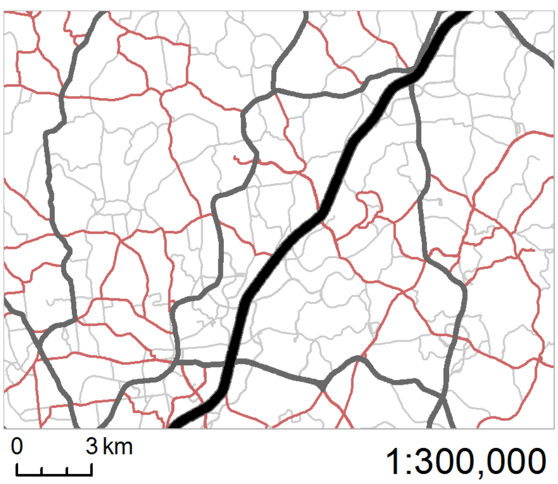
the sample area with denser road networks. These results imply that thinning should proceed by partitioning the data either by a hierarchy of road categories, by density partition, or by a combination of the two.

Initial testing shows very good results for thinning within a road category hierarchy. Figure 3 shows two levels of local roads with collectors in red (14,000m thin in Figure 3a) and other local roads in light gray (3,000m thin in Figure 3b), removing local roads that are part of itineraries less than 3,000m in length. This type of categorical thinning may be used to create a visible difference in line symbols for a map (such as different line widths), or to create a hierarchy of label styles for line symbols, or both (Figure 3c).

a)



b)



c)

Figure 3: Road thinning for hierarchy. Local roads are thinned using a) 14,000m (red) and b) 3,000m (lightest gray), and c) in combination. U.S. and State Routes shown with darker, wider lines.

To systematically establish that output scales are appropriate for each thinning, the basic equation for the Töpfer and Pillewizer (1966) Radical Law was inverted and applied to road length, rather than to number of roads, for consistency with previously published approaches to pruning hydrographic flowlines (stream channels) based on upstream drainage area (e.g., Stanislawski, 2009; Buttenfield et al., 2011):

$$\text{denominator of target scale} = \frac{(\text{length of source roads})^2 \times (\text{denominator of source scale})}{(\text{length of target roads})^2}$$

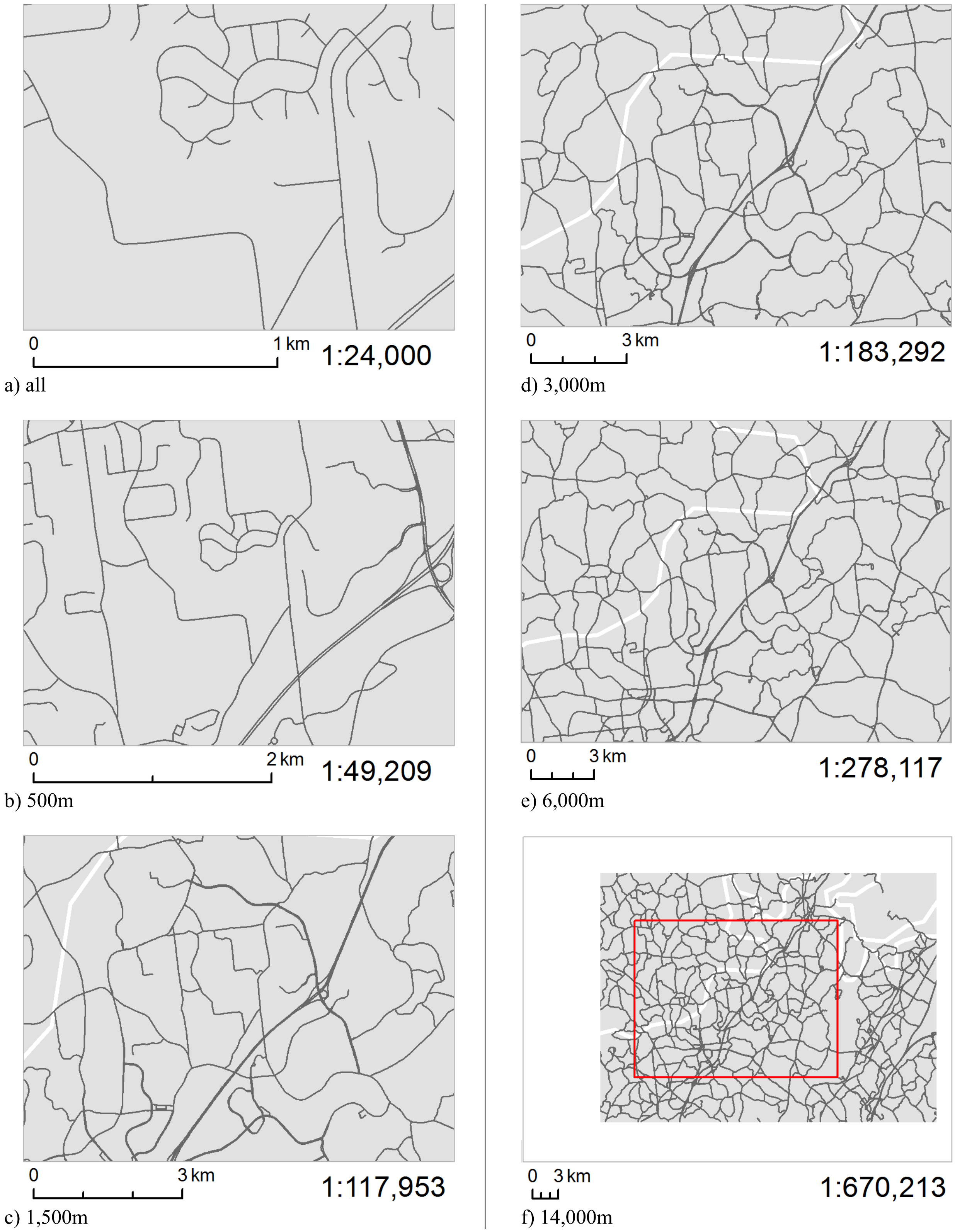


Figure 4: Thinning results mapped at scales calculated as suitable for each level of thinning using the Radical Law

Table 1 compares recommended scales interpolated from the Esri help files with Radical Law computations. At larger mapping scales there is good correspondence between recommended scales, but as minimum itinerary lengths exceed 1,500m, the Radical Law directs mapping toward relatively larger scales, eventually exceeding a Scale Factor of 2.0. The Scale Factor is a ratio of two map scales, often utilized in map projection studies to indicate relative scale distortion (Snyder, 1994). The relationship is not monotonic, and begins to drop back towards 2.0 beyond a mapping scale of 1.4M. It remains to be tested if the Scale Factor will stabilize for small scale mapping at 2.0.

Table 1. Map scale recommendations for roads thinned to a progression of minimum itinerary lengths.

Minimum Itinerary Length (m)	*Esri Recommended Map Scale**	*Scale from Modified Radical Law*	*Scale Factor*
250	25,000	24,000	1.04
500	50,000	49,209	1.01
1,500	150,000	117,953	1.27
3,000	300,000	183,292	1.64
6,000	600,000	278,117	2.16
14,000	1,400,000	670,213	2.09

* Recommendation for organic, non-gridded road pattern (ArcGIS Resources, 2012b), which approximately describes the sample area road network.

Road Labeling Using Thinning

Road elimination and label hierarchy may be guided by thinning through scale by establishing four basic representation states, outlined in Figure 5. Labeling was accomplished using the Esri Maplex labeling engine. Some road lines (i) are set invisible by the thinning tool (white, to the left of the ends of gray bars); (ii) other roads are drawn but not labeled (across the extent of each gray bar); (iii) some roads have smaller labels with lower placement priority (orange bars); and (iv) the most important local roads have larger labels and higher placement priority (reddish bars toward right of Figure 5).

These line and label decisions were reached by means of database enrichment in ArcGIS, by adding an attribute whose values equal the sum of numerous thinnings, providing invisibility-flag frequencies among eleven thinning options recorded in a single field. This allowed use of multiple thins in concert, both as symbol classes within one layer, and as corresponding labeling classes for Maplex. The alternative, to thin layer by layer and create a separate binary invisibility setting each time, seemed (in comparison) to be cumbersome and more difficult to interpret for symbol and labeling purposes. Scales smaller than 150K seemed best treated using a single level of local road labels, but all scales benefited from directing Maplex

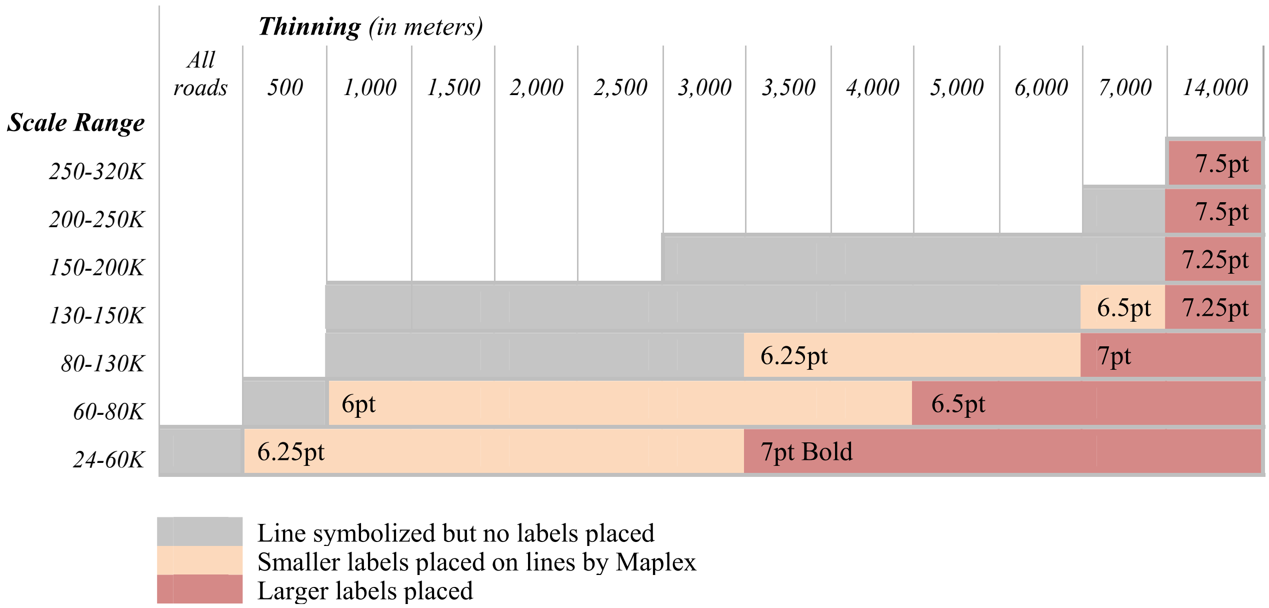


Figure 5: Example recommendations for labeling thinned roads through scale (based on the Atlanta sample area) show type specifications for labels at two levels of importance (red and orange). Gray bars indicate road features which appear at a given scale but are not labeled.

to omit labels from the smallest, least connected road lines. For example, even at 24K labels are omitted from roads not included in the 500m thinning, though these features are drawn on the map.

Figure 6 demonstrates labeling at exemplar scales: all local roads are shown with the same line symbol, and collectors are shown with larger red type. Other moderately important local roads are labeled with smaller dull-orange labels, and minor local roads are not labeled. The darker and wider road lines representing Interstates, U.S. Routes, and State Routes are assigned using road categories rather than thinning levels. These sample maps associate with specific rows in Figure 5. For example, Figure 6b at 110K corresponds to a middle bar (80-130K) of Figure 5. This bar shows decisions to set roads invisible using 1,000m thinning, to show smaller labels for roads thinned to 3,500m, and apply larger labels on roads thinned to 7,000m.

Summary and Topographic Context

This paper has explored the use of adaptive thinning of road features for mapping scales ranging from 1:24,000 to 1:1,000,000. Thinning methods are applied to road features and labels for *The National Map* of the United States. Adaptive thinning removes features by feature hierarchy and network connectivity, yet preserves characteristic urban/rural local density patterns that can be lost through simple category elimination. The paper demonstrates thinning for label hierarchies within road categories, improved preference in placement for more important road labels, and selective removal of labels through scale. Use of the Radical Law guides matches between thinning parameters and suitable scales of representation.

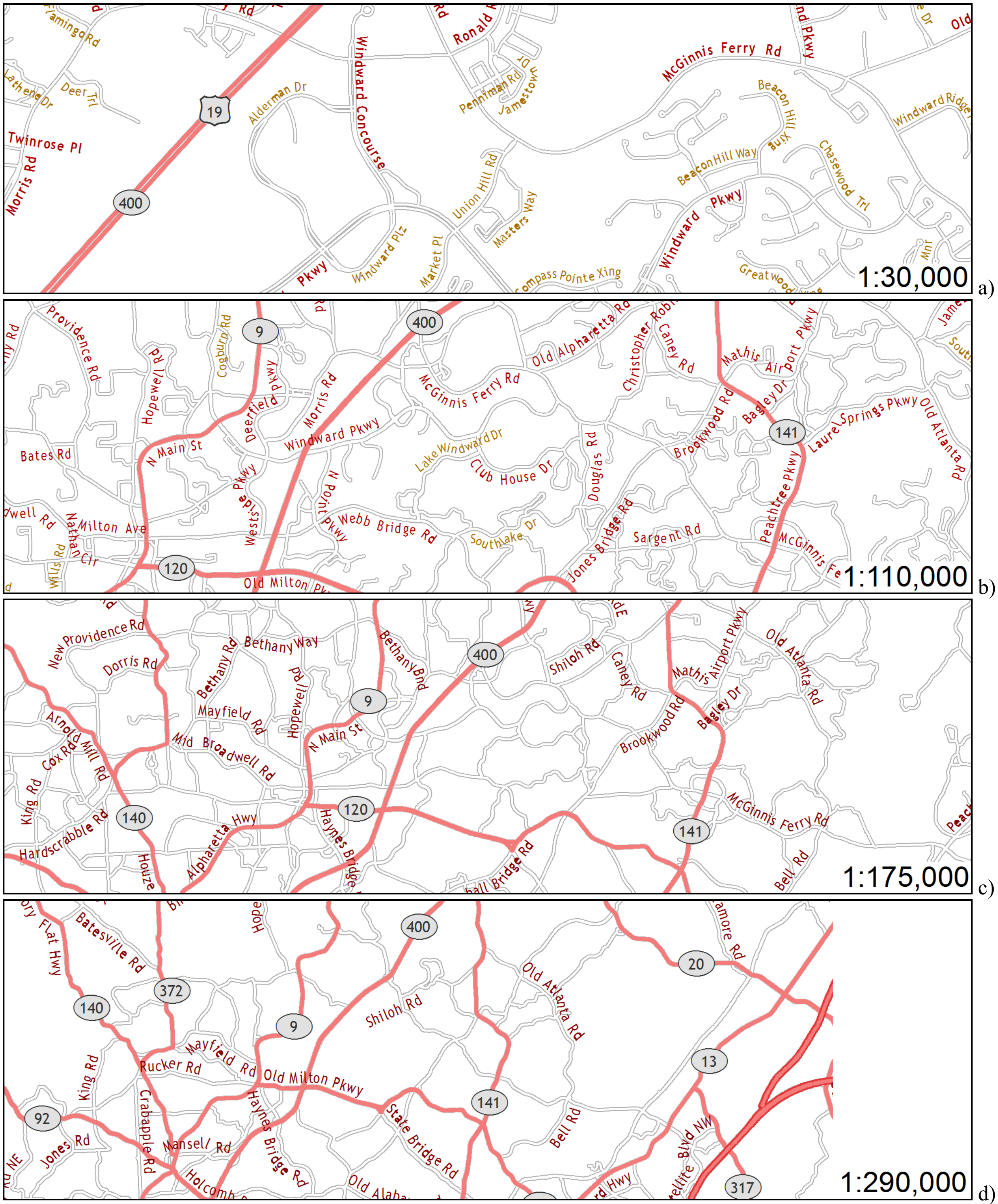


Figure 6: Label placement guided by thinning levels: a) labels for the 24-60K range shown at 30K; b) 80-130K range shown at 110K, c) 150-200K range shown at 175K, and d) 250-320K range shown at 290K. Smaller dull orange labels for shorter itineraries are given secondary priority in the labeling, so collector roads (red labels) are more likely to be named. Label colors in this figure reflect color coding in Figure 5.

In thinning transportation networks for mapping at smaller scales, it is important to keep in mind that road features and their labels function within a busy visual context, with many possible layer combinations available for topographic mapping. Labels are expected to be readable over both detailed and saturated backgrounds, and often in combination with orthoimagery, hillshading, and land cover. Beyond graphical challenges, control over Maplex label placement is needed to ensure that a town is not characterized by the names of minor alleys and cul-de-sacs along its perimeter, but rather by the names of main roads through town which will help readers to orient themselves on the map. Road hierarchy and label hierarchy are fundamental to high quality mapping, and thinning tools have the potential to automate this basic goal for cartographic representation using GIS tools and national datasets.

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