CO-086

AN EVALUATION OF THE IMPACT OF CARTOGRAPHIC GENERALISATION ON LENGTH MEASUREMENT COMPUTED FROM LINEAR VECTOR DATABASES

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1. INTRODUCTION

Since three decades, a significant number of researches have been conducted in the field of spatial data quality evaluation (Devillers et al, 2010). Many studies have been published on the estimation of positional accuracy (see, for instance, Burrough, 1986; Guptill and Morrison, 1995; Vauglin, 1997; Hunter and Goodchild, 1997; Shi and Liu, 2000) and indicators for its description are provided in the ISO norm 19138 (ISO, 2006).

The information on positional accuracy of geographical objects is fundamental to be communicated to the final user, as it evaluates how far a coordinate is from its real location. Another important information concerns the accuracy of length and area measures performed from a given data set. Indeed, many applications in GIS rely on the computation of these measurements, e.g. a travel time by car, or a population density in an administrative entity.

Imprecision in length and area computation has been studied by different researchers. For instance, (Chrisman and Yandell, 1988) proposed a statistical model to estimate the error in area computation, (Griffith, 1989) modeled the impact of digitization error on distance and area computation, and (Leung et al, 2004) developed a general framework for error analysis in measurement-based GIS. Besides these important scientific contributions, it is still very complex to communicate imprecision information in length and area computation to the final user, because the geometry of geographical objects can be affected by different processes which impact these computations. The problem is that the knowledge on positional accuracy does not allow to compute the accuracy on length and area measurements because the distribution of errors of position is not homogeneous and greatly depends on the processes used to build the data.

To be able to estimate length and area accuracy, all the possible sources of geometric uncertainty need to be modeled. Indeed, different causes in the production and representation processes of vector objects impact measurements.

In term of representation processes, we know that measurements can be impacted by:

- the projection system used
- not taking account of the terrain, involving an under-estimation of lengths and areas

For the production processes, measurements are also impacted by:

- the digitizing precision of the operator, usually involved by the scale of capture
- the precision of the sensor, if the database is produced using a GPS
- the polygonal approximation of curves, when objects represented are curved
- effects of cartographic generalisation, if the database is captured from maps

If a final user wants to assess the measurement imprecision of its database, he has to take into account all these potential sources of error. To fit with this requirement, our research aims at developing a general model which takes into account all the sources exposed above, and to quantify their respective impact, in order to provide information on measurement imprecision.

The expression of digitizing error, and polygonal approximation has already been presented in (Girres and Julien, 2010) and the general model in (Girres and Ruas, 2010). In order to complete the expression of production processes impact on measurements, a study of cartographic generalisation effects has to be conducted. In this context, this paper proposes a method to evaluate the effect of cartographic generalisation on length measurement, focusing on road networks. The general methodology, as far as the different steps of the evaluation, is presented afterwards.

2. ASSUMPTION AND GENERAL METHODOLOGY

It is well known that cartographic generalisation affects measurements computed on vector objects (Blakemore, 1984; Joao, 1998, Bard, 2004), by modification of their shape and/or position. As shown by (Touya et al, 2010), we know that specific generalisation processes are used according to a specific spatial context. For instance, different automatic generalisation processes have been developed for mountainous (Mustière, 2001), rural (Duchene, 2004) or urban (Ruas, 1999) areas.

In this research, we assume that the quantity of length error in a linear vector dataset varies according to the production scale and the spatial context. Thus, the goal of this paper is to propose a method, in order to define a statistical law to assess the length error in linear vector databases, as presented in formula 1.

(1) *Length Error = f(scale, context, type of object)*

In this function, two unknowns need to be defined:

- The spatial context of objects
- The scale of representation, which determines the level of generalisation

Methods to delineate the spatial context using external datasets are presented in section 3. For roads, three kinds of context are defined because we know that the effects of generalisation are not the same in urban, rural and mountains areas.

- In urban area, streets are removed; some thin areas are enlarged. As the consequence, the positional accuracy of roads is a bit "degraded" (Figure 1a).
- In mountains areas – or to be more precise in slope areas – road bends can overlap (Figure 1b). As a consequence some bends are removed and others are enlarged. We can then make the hypothesis that generalisation has an impact on road length.
- In rural area, conflicts are less important, the effect of generalisation is certainly smaller.

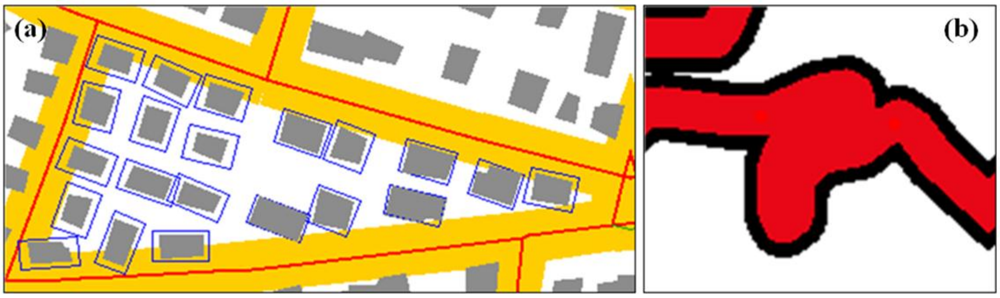

Figure 1. Examples of symbols overlap (from Ruas, 1999) in urban area (a) and on a mountain road (b)

The determination of the level of generalisation is presented in section 4, using methods based on the symbol thickness. In order to build the statistical law, a study of the distribution of length errors is realised, based on comparisons between generalised datasets (at different scale levels) with a more accurate and nearly not generalised one, considered as a reference. The methodology of comparisons, performed in the three spatial contexts evocated above, is exposed in the section 5.

The process of length imprecision estimation is then divided in two steps:

- The elaboration of the function using length comparisons between generalised datasets and a reference dataset, at different scale levels and spatial contexts (Figure 2a)
- The use of this function in order to evaluate length imprecision in a dataset, by determining its scale level and spatial contexts (Figure 2b)

Experimentation is performed using different representations of a road network in the French department of Pyrénées-Atlantiques.

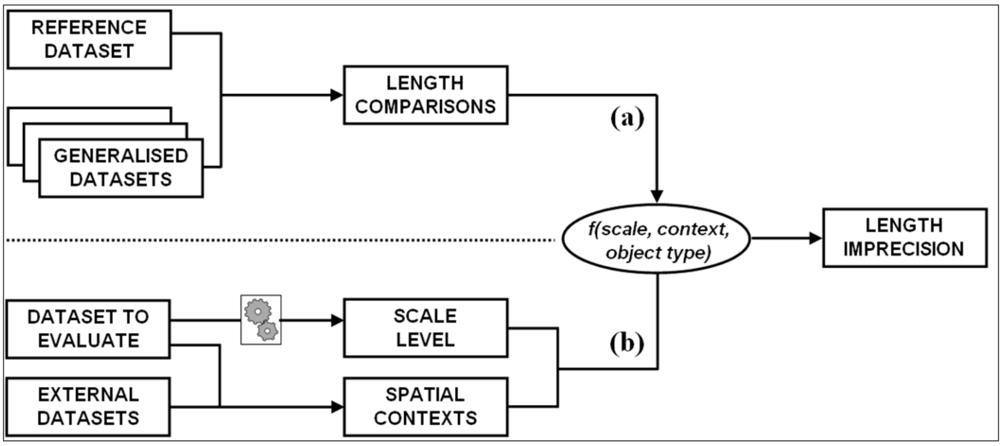

Figure 2. Two-steps methodology for the estimation of length measurement imprecision

3. SPATIAL CONTEXT DETECTION

As exposed previously, we assume that the effects of cartographic generalisation vary according to the spatial context. Thus, to allow the estimation of length measurement imprecision, the delineation of mountainous, urban, and rural areas needs previously to be done. Because the model is supposed to work for any user, without acquisition of paying data, all the external datasets used in this part are freely downloadable on the Internet.

3.1. Mountainous areas

As denominated by « mountainous areas », we actually look for detecting areas with important differences in altitude, because they strongly impact roads (by bend overlaps…) involving generalisation processes. Several methods for the automatic delimitation of mountainous areas have already been developed, as the one proposed by (Chaudhry and Mackaness, 2008a). For this study, an original method is used, based on contour lines.

Mountainous area delimitation is realised using contour objects extracted from the SRTM (file srtm_36_04.tif), a 90*90 meters ground resolution digital elevation model, downloaded from http://www.cgiar-csi.org. Contour lines are created with an equidistance of 40 meters, for the French department of Pyrénées-Atlantiques (Figure 3), using Quantum GIS software (http://www.qgis.org/).

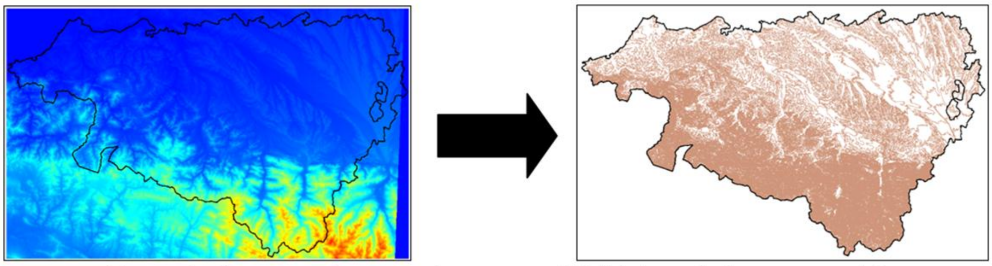

Figure 3. Creation of contour lines using SRTM digital elevation model

A grid approach is developed to delineate mountainous areas. A 500*500 meters cell size grid is created on the entire study area. In each cell of the grid, two different criteria are tested in order to determine if the cell is considered as "mountainous" or not. The first criterion consists in determining the maximum altitude difference between contour lines intersected by the cell, as exposed in formula 2.

$$\text{(2)} \qquad \text{AltMax} - \text{AltMin} > T$$

Where AltMax and AltMin are respectively the maximum and minimum altitudes in the cell and T the threshold to determine if the cell is considered as mountainous

The second criterion, proposed by (Jaara and Lecordix, in press), takes more into account the altitude heterogeneity in each cell, as shown in Formula 3.

$$\text{(3)} \qquad 2 * \text{AltMax} - \text{AltMin} - \text{AltAve} > T$$

Where AltMax, AltMin and AltAve are respectively the maximum, minimum and average altitudes in the cell and T the threshold to determine if the cell is considered as mountainous

After different tests of the two criteria and validation by comparing with maps, the second criterion appeared obviously as the most realistic, using a threshold of 200 meters for a 500*500 meters resolution cell size (Figure 4a).

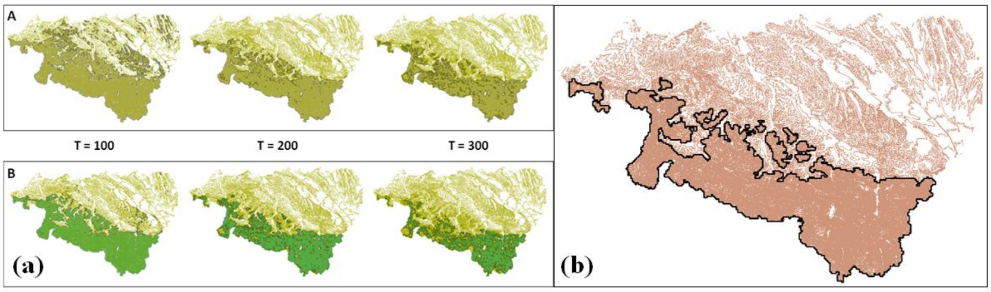

Figure 4. (a) Comparisons between the criteria A (formula 2) and B (formula 3) for different threshold values. (b) Final mountainous areas after cleaning.

In order to provide a clean and homogeneous delineation of mountainous areas (Figure 4b), two post processing are performed:

- Suppression of small polygons (area < 4.000.000 sq. meters)
- Suppression of holes in polygons

The delimitation of mountainous areas was successful in the study zone using a threshold of 200 meters for a resolution cell size of 500*500 meters. Nevertheless, in order to validate the method, it looks important to perform similar experimentations in others areas, using different cell sizes.

3.2. Urban areas

Urban area delimitation has been widely studied in the field of cartographic generalisation. Different methods of identification of urban boundaries have been already developed, based on the proximity of buildings (Boffet, 2000; Chaudhry and Mackaness, 2008b), or using road networks density (Walter, 2008).

Because buildings or road networks datasets are not systematically available and/or complete on a given area, we decide to use the freely downloadable Corine Land Cover vector database (see Figure 5a). This database, initiated by the European Environment Agency, proposes a land cover classification for European countries in 44 classes. Two of them are provided to delineate urban areas: Continuous Urban Areas and Discontinuous Urban Areas (respectively identified by the codes 111 and 112). A simple Union of these two layers is performed to provide the delimitation of urban area for the study (Figure 5b)

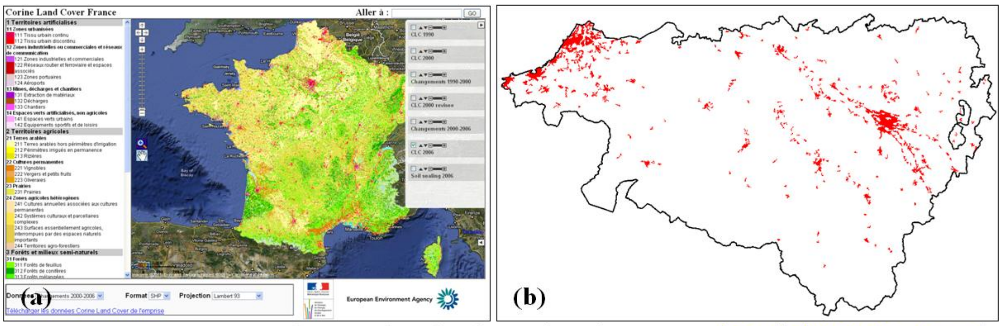

Figure 5. (a) Corine Land Cover download interface for France (http://sd1878-2.sivit.org/)
(b) Urban Area Delimitation for the study

Because the Corine Land Cover database is only provided for European Union, the question of the possibilities to delineate urban areas for the other continents needs to be asked. The Global Land Cover Facility (GLCF) also provides land cover classifications and integrates a class Urban and Built at a minimal resolution of 1 square kilometer. Otherwise, methods evocated above, based on buildings and road networks - if available - can be performed.

3.3. Rural Areas

In this study, rural areas are defined as the complementary part of the union between mountainous and urban areas, as exposed in Formula 4.

$$(4) \qquad RA = \overline{MA \cup UA}$$

Where RA, MA and UA are respectively Rural, Mountainous and Urban Areas

After delimitation of the three spatial contexts, a method to estimate the scale of representation of the dataset is proposed, in order to evaluate its level of generalisation.

4. ESTIMATION OF THE LEVEL OF GENERALISATION

After presenting methods to detect the spatial context of objects, we describe in this section how to evaluate the level of cartographic generalisation in a dataset. The level of generalisation of a map mainly depends on the scale, the size of the symbol and the spatial context. Moreover, according to a given problem of representation (symbols overlap for instance), specific operations are performed (displacement, bends removal, bends enlargement…). In this way, knowledge on cartographic generalisation operations can help us to estimate the scale of representation, when the symbol size is specified.

Thus, two original methods are presented in this section to try to estimate the scale of representation of geographic objects, using samples of road networks.

4.1. Road symbols overlap

The first method is related to a classical problem in cartographic generalisation: the representation of close roads. As illustrated in Figure 6, considering that the symbol size is constant, when two roads are close enough, if the scale is reduced, both symbols will overlap, involving an operation of displacement of roads axis for a good representation of the symbols on the map.

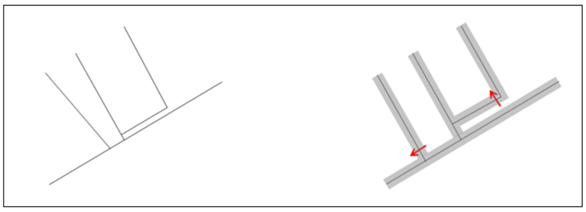

Figure 6. Displacement of roads axis to avoid symbols overlap

We assume that the minimal distance computed between two roads axis in a generalised dataset is function of the symbol size and the scale of representation, as exposed in Formula 5. According to map usages, a gap can be provided between two road symbols, to facilitate visualization.

$$(5) \qquad MRD = (2*SSW + G) / MS$$

Where MRD is the Minimum Road Displacement (in meters), SSW is the Semi-Symbol Width (in mm), G the Gap (in mm) between the two symbols on the map, and MS the Map Scale.

Using Formula 5, we can estimate the scale of representation of the map when:

- the minimum deviation between close roads is computed (i.e. MRD)
- the symbol size is specified (i.e. SSW)

To automatically operate this estimation of the scale of representation on a road network dataset, a process has been developed with the Geoxygene Library (Bucher et al, 2009).

This estimation supposes the knowledge of the symbol size. We used specifications of roads representation in two maps produced by the IGN, the French National Mapping Agency, presented in Table 1.

Road Type	**1:100 000**	**1:250 000**
Motorway	1.5 mm	1.5 mm
Large Principal or Regional roads	0.9 mm	1 mm
Narrow Principal or Regional Roads	0.7 mm	0.75 mm
Pathway	0.25 mm	0.25 mm

Table 1. Road symbol width specifications for maps produced at the scales 1:100 000 and 1:250 000

An algorithm is developed based on the symbol size and the possible scale of representation. In order to locate close roads, potentially affected by symbols overlap, a topological network is created with the road network (Figure 7a). In a second time, intersections of roads (considered as nodes with three or more connected arcs) are selected (Figure 7b). Close intersections, with a distance smaller than 400 meters, are then selected (Figure 7c). All arcs connected to these intersections are finally selected (Figure 7d). For these arcs, we compute a buffer using the product between the selected symbol size and the scale of representation (Figure 7e). If there is no overlap between buffers, the scale is incremented and the process starts again. The algorithm stops when symbols overlap occur between two buffers (Figure 7f), determining an estimation of the scale of representation.

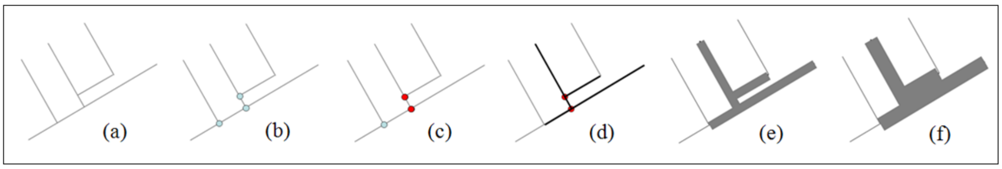

Figure 7. Process of estimation of the representation scale of a generalised road network using symbols overlap

In order to validate the proposed method, experimentations have been performed on two databases samples, representing the same road network at two different scales: 1:100 000 (TOP100 dataset) and 1:250 000 (Regional Map dataset). The initial tested scaled is 1:10 000, incremented by 10 000. For each scale, the number of overlaps is computed.

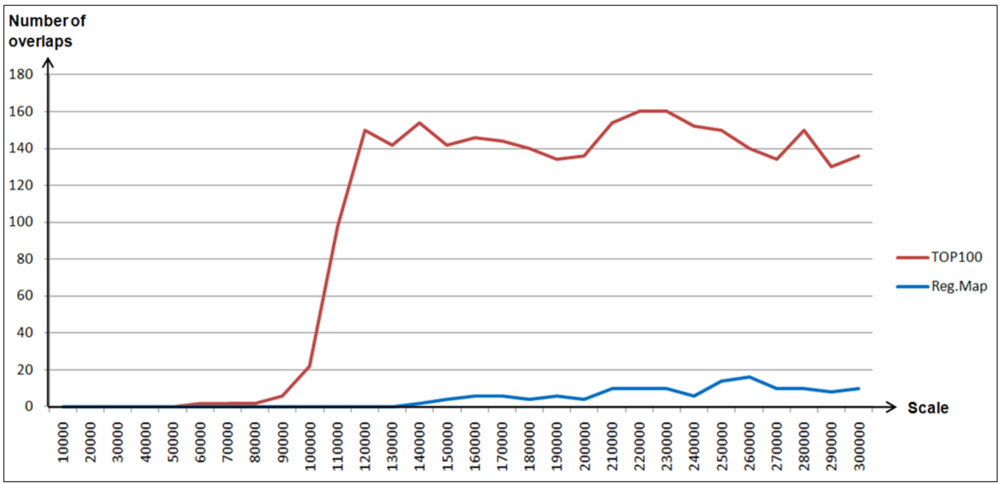

Figure 8.Number of road symbol overlaps detected according to the scale on the two experimented datasets (TOP100 in red and Regional Map in blue)

As exposed in the Figure 8, this method proposes relevant results for the TOP100 dataset. Even if two overlaps are detected at the scale 1:60000, the number significantly increases at the scale 1:100000, the representation scale of the source map. This evaluation is not so obvious on the Regional Map dataset, even if a small peak is observed at the scale 1:260000.

Thus, this method provides interesting information to estimate the scale of representation of a generalised dataset. However, this method is effective when the road network is relatively dense, but in mountainous or rural areas, if roads are not close enough, this method becomes useless. Then, a second method is proposed, based on road bends symbols coalescence.

4.2. Road bends symbol coalescence

The problem of bends symbol coalescence is also a classical problem in cartographic generalisation. As illustrated in Figure 9 by (Mustière, 2001), when bends are too narrow, a symbol coalescence occurs, avoiding a good visualization of the road sinuosity on the map.

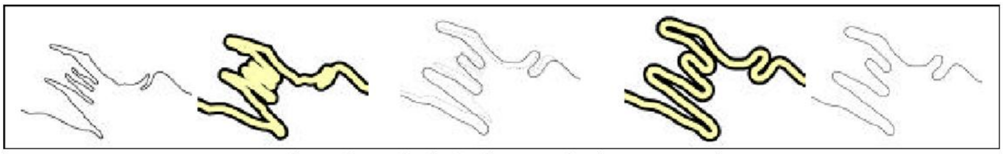

Figure 9. Comparison of road symbols before and after generalisation (Mustière, 2001)

Two generalisation processes are proposed in order to provide a good visualization: bends removal or bends enlargement. In order to detect when it is necessary to activate these generalisation processes, (Mustière, 2001) proposed a method based on the maximum tolerated symbol coalescence in road bends. As evocated in Figure 10, when the distance D between the interior of the bend and the symbol boundary is longer than the distance presented in formula 6, the road symbol is considered coalescent and generalisation process needs to be activated.

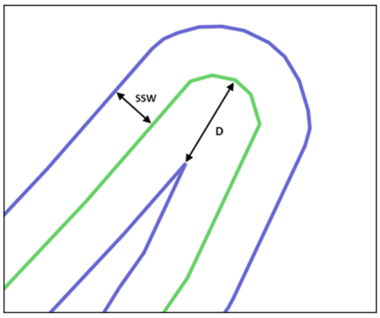

Figure 10. Detection method of road bends symbol coalescence

$$(6)\ D > SSW * 1.7$$

Where SSW is the semi symbol width

Thus, in order to estimate the scale of representation of generalised objects, we assume that in a road dataset, the maximum tolerated distance between the axis of the road and the symbol boundary complies with Formula 6.

To implement this method, an algorithm is developed based on the symbol size and the scale of representation. As in the symbols overlap method presented above, a buffer is build for each road segment, according to map specifications. For each scale experimented, the algorithm compute the number of bends coalescence (i.e. if the distance between the axis of the road and the boundary of the symbol is longer than the distance D), in order to carry out the scale of the data source.

Experimentation is performed using the same road networks than in the previous scale estimation method: 1:100 000 (TOP100 dataset), 1:250 000 (Regional Map). Also, the initial tested scale is 1:10 000, incremented by 10 000.

As presented in Figure 11, results show that the bends symbol coalescence are already detected at large scales in a small quantity. For the TOP100 dataset, the number of symbol coalescences strongly increases at the scale 1:100000 (i.e. the representation scale of the map), which shows the interest of the method. Results are not as significant for the Regional Map dataset. The number of coalescences detected rises at the scale 1:150000, which is below the real representation scale (i.e. 1:250000). The impact of database generalisation, involving the removal of small roads, can be responsible of the low detection of bends symbol coalescence for the Regional Map. Indeed, most of the interesting bends for this method are located on small sinuous roads.

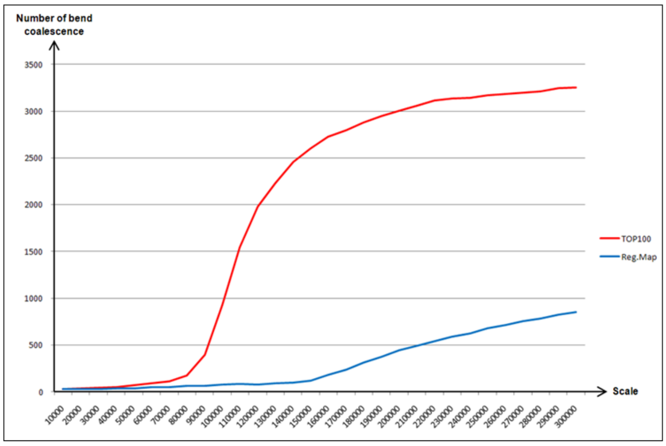

Figure 11. Number of bend coalescence detected according to the scale in the two experimented datasets (TOP100 in red and Regional Map in blue)

These results, as illustrated by the experimentation on the TOP100 dataset, show that this method can also be relevant to estimate the representation scale of a generalised road network dataset, especially in mountainous areas. Nevertheless, the example of the Regional Map illustrates that the impact of database generalisation, and by consequence the completeness of the dataset, can limit the use of this method for a good scale estimation.

5. ELABORATION OF THE LENGTH IMPRECISION FUNCTION

As exposed in the second section of this paper, the objective of this study is to elaborate a function, allowing the estimation of the quantity of length error in a road dataset, caused by effects of cartographic generalisation, according to the spatial context and scale of representation. Methods to detect the spatial context and the scale of representation have already been presented in sections 3 and 4. The last section of this paper consists in the elaboration of the function of length imprecision, using comparisons between generalised road datasets with a more accurate one, considered as reference. Principles of comparisons are previously exposed, followed by results of comparisons and the elaboration of the function.

5.1. Datasets comparison method

In order to compare the distribution of length differences between a generalised dataset and a reference, an original method is proposed. Indeed, the easiest method would consist in comparing the lengths of entire corresponding sections in the two datasets, located between two intersections. The main problem is that on a generalised dataset, according to the scale of representation, many of these intersections can be removed. Thus, a method of comparison by sections has been developed for this study (Figure 12).

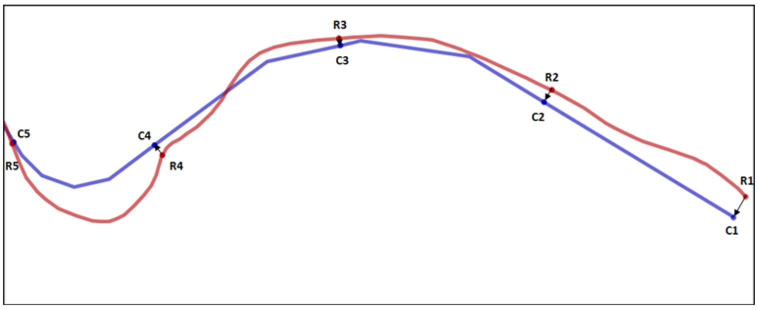

Figure 12. Road networks comparison method using sections

After a preliminary matching of the both road networks, using the algorithm developed by (Mustière and Devogèle, 2008), the reference dataset R is divided in sections of equal length, parameterized by the user. The extremities of these sections (R1, R2…) are then projected on the generalised dataset (C1, C2…), in order to divide it in the same number of sections.

The length difference between the corresponding sections is then computed and stored in a database, in order to study their distribution with classical indicators (average, median and standard deviation of length differences). Such comparisons are performed in the three spatial contexts evocated in section 3, using different length values for the segmenting of the reference dataset.

5.2. Road networks comparisons results

Comparisons are performed using three generalised datasets, all representing the road network of the French department of Pyrennées-Atlantiques: BDCARTO (1:50 000), TOP100 (1:100 000) and Regional Map (1:250 000). The BDTOPO dataset is used as a reference to perform comparisons. The Table 2 exposes results of comparisons according to the parameterized segmenting length of the reference dataset. For urban areas, the maximum segmenting length computed is 600 meters. Indeed, in urban areas, few road sections observed are longer than this distance. For mountainous and rural areas, segmenting lengths are performed until 2000 meters.

	Mountainous						Urban						Rural					
Sections Length	Regional Map		TOP100		BDCarto		Regional Map		TOP100		BDCarto		Regional Map		TOP100		BDCarto	
	m.	%	m.	%	m.	%	m.	%	m.	%	m.	%	m.	%	m.	%	m.	%
200	8,9	4,4	9,1	4,5	1,0	0,5	10,4	5,2	5,7	2,8	0,3	0,1	8,8	4,4	6,6	3,3	0,4	0,2
300							14,9	5,0	9,0	3,0	0,5	0,2						
400	24,1	6,0	23,1	5,8	3,8	0,9	20,5	5,1	12,4	3,1	0,8	0,2	17,6	4,4	14,0	3,5	1,5	0,4
500							24,6	4,9	16,5	3,3	0,3	0,0						
600	36,4	6,0	34,3	5,7	5,7	0,9	28,5	4,7	18,8	3,1	0,9	0,1	26,9	4,5	21,8	3,6	2,7	0,5
800	48,3	6,0	45,6	5,7	8,2	1,0							35,6	4,5	29,5	3,7	3,7	0,5
1000	61,2	6,0	58,9	5,9	9,4	0,9							44,0	4,4	37,2	3,7	4,5	0,4
1200	71,3	5,9	68,5	5,7	13,3	1,1							53,2	4,4	46,3	3,9	5,4	0,4
1400	79,3	5,7	80,2	5,7	14,3	1,0							63,1	4,5	54,9	3,9	7,3	0,5
1600	93,3	5,8	89,1	5,6	14,3	0,9							72,1	4,5	65,6	4,1	8,7	0,5
1800	107,3	6,0	105,0	5,8	17,3	1,0							82,4	4,6	74,0	4,1	9,8	0,5
2000	114,7	5,7	116,4	5,8	20,1	1,0							89,7	4,5	84,3	4,2	9,4	0,5

Table 2. Average length errors for the three datasets experimented, according to the spatial context and the reference segmenting lengths in absolute (meters) and relative (%) values

Results show that in mountainous area, length imprecision of road networks is more important than in rural or urban areas, whatever the scale is. The table also shows that there is no significant length difference between road sections located in urban or rural areas.

But according to generalisation experts, impacts of cartographic generalisation in urban area are more characterized by operations of displacement of objects, which don't impact significantly their lengths but much more their position. The computation of appropriate distance (i.e. Hausdorff distance and Mean Distance, see Vauglin, 1997) to evaluate positional effects would constitute an interesting complement for this study.

Results clearly show that the most important factor of imprecision is the level of generalisation, involved by the scale of representation, followed by the spatial context. As shown in Figure 13a, we can easily observe that between TOP100 and BDCARTO datasets, the average imprecision values are much more important for TOP100 datasets in any spatial context. This figure also shows that the average length difference is not so important between TOP100 and the Regional Map road networks, except in urban areas.

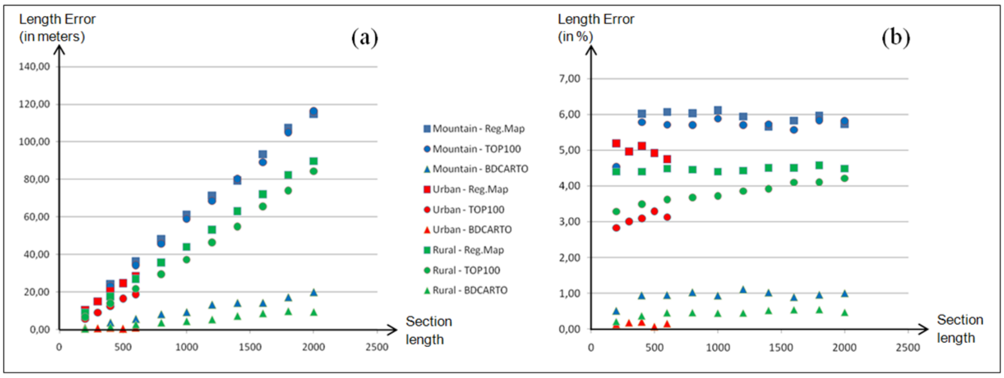

Figure 13. Absolute (a) and Relative (b) average length error for the three datasets experimented according to the reference segmenting length and the spatial context

The Figure 13b presents a representation of the average relative length error, in percentage of the reference segmenting length. This representation shows that in mountainous areas, length measurements performed on road objects are on average underestimated by about 6% at the scale 1:250000, 5.5% at the scale 1:100000 and 1% at the scale 1:50000. In urban areas, they are on average underestimated by about 5% at the scale 1:250000 and 3% at the scale 1:100000; and in rural areas, by about 4.5% at the scale 1:250000, 3.5% at the scale 1:100000 and 0.5% at the scale 1:50000. This formalization of the average relative length error is relevant in order to elaborate the function of length imprecision estimation for generalised road networks datasets.

5.3. Estimation function

As assumed in this paper, the imprecision length of a generalised dataset varies according to the spatial context and the scale of representation of objects in the original map. This study, elaborated with datasets produced for the scales 1:50 000, 1:100 000, and 1:250 000 in three different spatial contexts (mountainous, urban and rural areas), allows us to represent the function of average relative length imprecision, as exposed in Figure 14.

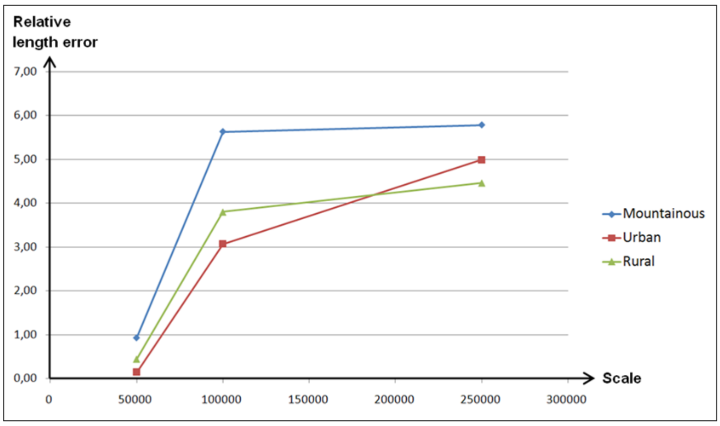

Figure 14. Function of the average relative length error for a road network, according to the spatial context and the scale of representation

Even if this representation is an approximation based on a specific experimentation, it provides a good complement of the results proposed by (João, 1998).

6. CONCLUSION AND FURTHER WORKS

This paper exposed a general method to estimate the impact of cartographic generalisation on length measurements on a road dataset, for which production processes include generalisation operations. The principal assumption of this research is that the quantity of length error varies according to the scale of representation and the spatial context of geographical objects. Experimentations based on comparisons demonstrate that length imprecision is involved primarily by the scale of representation, and secondarily by the spatial context, especially in mountainous area.

Several methods have been developed to delineate the spatial context, to estimate the representation scale of the source map, or also to compare datasets lengths using sections. Further developments are still necessary to validate scale detection methods.

On a methodological point of view, the function of estimation of length imprecision has been created using prior comparisons, with different datasets variously affected by database generalisation. Thus, length imprecision results can only be accepted for homologous objects, but neither on an entire dataset. Indeed, not taking into account the completeness of the dataset would represent a methodological failure. For instance, the length imprecision between two points, using two different road networks datasets is not only affected by bends generalisation, but also by network generalisation (which is also a generalisation process) involving the presence or absence of road segments. Further investigations needs to be realised on the impact of completeness in the computation of length for a road network.

The methodology has been only applied on road networks. To complete the study of the impact of cartographic generalisation, it looks fundamental to develop similar studies on other themes represented in maps, for both linear and polygonal objects.

Thus, this original work, already initiated by (João, 1998), needs to be completed by further investigations, which compose consistent contributions for the development of a general model of estimation of geometric imprecision impact on basic measurements.

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