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Simplification methods for line and polygon features in mobile navigation systems for inland waters

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Abstract

Mobile navigation for inland shipping is an example of a GIS system dedicated for recreational users using inland waterways. Developing this system is a primary purpose of the research project "Mobile Navigation for Inland Waters" funded by the National Centre for Research and Development under the program LIDER. System assumptions include the development of a dedicated model of mobile cartographic presentation, taking into account the generalization of data. This article is focused on simplification of line and polygon features, included in the spatial data model MODEF (MObinav Data Exchange Format), which is used in the created system. During the simplification of line features, the Douglas-Peucker algorithm was mainly implemented. During the simplification of polygon features, a simplification method was applied, maintaining the basic shape and size of the objects. A simplification tolerance parameter and a parameter determining the minimum area of the object was also used. In addition, objects within a certain distance were merged. A smoothing tool for the shape and size of buildings and the PEAK method (Polynomial Approximation with Exponential Kernel) were used as well. Furthermore, a selection tool was employed and features with minor importance to the user were deleted during navigation mode. Given the requirements of the future user of the system, a separate model simplification for each of the layers of the system was created; these models are combinations of the methods listed above. The overriding factor that has been taken into account during the research of simplification methods, was the limitation of the sharpness of human eyes. The study of generalization methods was carried out in ArcGIS software.

Introduction

Navigation systems for mobile devices have now become one of the most popular types of mobile application.

They allow quick and easy route planning as well as the location of user-selected targets on a map. In addition to traditional automobile navigation systems, similar interfaces designed for hiking and bicycle navigation, and navigating cities by means of public transport, have become more and more popular. A significant increase in popularity can be noted in the area of recreational water tourism, including that on inland waters.

As part of the R&D project LEADER IV program, supported by the National Centre for Research and Development (NCBiR) of Poland, MOBINAV – a system of mobile inland water navigation – has been created. The main purpose of the system is to facilitate the navigation of inland waterways for tourist and recreational use. The system involves the processing of spatial information, including that gathered from open sources, and a mobile map presentation based on a number of geocompositions with their components, triggered by subsequent cartographic events.

During the development of the system model, all of the needs of inland waterways users and the technical capabilities of mobile devices were taken into account.

The analysis also included access to spatial data and the abilities and limitations of the small screens of mobile devices, such as smart phones, with respect to visualization. As a base on which to model the system, a methodology described in (Gotlib, 2012) was modified. As a result of the modification: 28 layers of spatial information were defined; more than 180 cartographic information transmission units (further CITU) were established; 10 geocompositions and 54 partial geocompositions were specified; and more than 50 cartographic events were compiled. SCAMIN and SCAMAX attributes of every object on a map, responsible for the appearance of the object or its disappearance from the geovisualisation window on a mobile device, were set. The value of each SCAMIN and SCAMAX attribute determines the scale of the display, both below and above which the object is not graphically represented on the screen. Both attributes have been taken from the coding standard for Electronic Navigational Charts S-57 (IHO S-57, 2014).

Analysing all of the above, several key conclusions have been drawn. One of them is the fact that setting only partial geocompositions, responsible for displaying a specific set of objects in the geovisualisation window of a mobile device at a specific scale, is insufficient and does not ensure the clarity of map content. Defining attributes SCAMIN and SCAMAX proved to be satisfactory in the case of point objects. For the purposes of the correct map interpretation, and to avoid the effect of "littering" a small screen with too much information, objects of linear and area geometry require the use of classical simplification algorithms.

This article presents a brief description of the model of spatial data, and describes methods of simplifying linear and area objects, depending on the scale of the map. The exemplary results obtained by the use of these simplifying models are shown.

The characteristics of the spatial data model

The MOBINAV mobile navigation system model is based on a known methodology from the literature pertaining to mobile road navigation (Gotlib, 2011), defining it as a set of dynamically changing geocompositions. However, different goals and needs are important for a user driving a car from those that are important for conducting navigation procedures on water. The modification of the road navigation model began with the definition of basic criteria.

In addition to the classic criteria, such as environmental conditions or palette of colours, the following was determined:

- criteria of usage: viewing the map, route planning and navigation procedures;
- type of water area: lakes (which is also open waters), rivers and harbour areas.

Also, in order to determine the detail level of the map it assumes: the use of a default set of map objects or the definition of its own set of layers. On the basis of the basic criteria, 28 classes of objects were determined. In addition to the standard layers, such as water, land, vegetation and buildings or roads, typical tourist objects are listed, such as marinas and harbours, and those characteristic to port infrastructure and waterways such as quays, locks, bridges and stream gauges (Włodarczyk-Sielicka, Kazimierski & Marek, 2014).

Taking into consideration the small and limited screen sizes of mobile devices and based on defined criteria of usage, 5 geocompositions were specified (for user mode and base mode):

- viewing the map,
- route planning,
- navigation in open areas (such as lakes),
- navigation on rivers,
- navigation in harbour areas;

all with the assumption of detail selected by the user or the system default. Each of these geocompositions has its own set of partial geocompositions, which are just a map presentation on a specific scale. The number of scales differs depending on the basic criteria. 54 partial geocompositions have been established. An example geocomposition: MOBIbase viewing the map has a set of six partial geocompositions: 1: 4000, 1: 10 000, 1:50 000, 1:100 000, 1:500 000 and 1:1 000 000. In contrast, geocompositions: MOBI_user navigation on the river has: 1: 2000, 1:4000, 1:10 000, 1:17 500 and 1:25 000. Partial geocomposition is a set of Cartographic Information Transmission Units (CITUs) properly arranged and ordered by their importance. CITU is the representation of the object on the mobile map. There are not only geometric objects such as road or water bodies, but also labels (names of water bodies), audio alerts and interface messages. Over 180 CITUs have been defined. The approach "geocomposition + partial geocomposition", specifying which objects will be visible at a certain scale on a mobile device, to some but not an entirely satisfactory extent, ensured the clarity of the resulting mobile map. This can be explained based on the example of the POI (Point of Interest) object, which should appear anywhere and at any scale. In the case of small scale geovisualisation on a mobile device screen, a large accumulation of POI objects appears, displayed overlapping one another, resulting in "clutter" on the map and a loss of clarity. An approach to improve the clarity of the map is to determine the values of SCAMIN and SCAMAX attributes. Both are responsible for the appearance or disappearance of objects after reaching a certain scale of display. Objects defined in the MOBINAV catalogue of objects are divided within a class into two categories. These categories are systematized according to the validity criterion of the spatial information, and on this basis the values of the SCAMIN and SCAMAX attributes are set. This approach gave satisfactory effects in the case of the point geometry objects. However, this approach turned out to be insufficient in the case of linear objects, *e.g.* road or rail, and areas, *e.g.* buildings. These objects require simplifying algorithms described later on in this article.

Selected generalization methods

In the mobile navigation system, the authors have focused on ensuring the effectiveness of the cartographic presentation, which is associated with the effectiveness of media content, usability of the map and its usefulness to the user. Generalization is a form of simplifying map content, depending on the purpose, the scale, the wealth of the content and the availability of the data. All of these factors have been included in the simplifying algorithm. The data generalization procedure for the mobile navigation system is carried out in several steps as shown in Figure 1: usage of the data directly relates to the selection of data source and the definition of partial geocompositions; scale also refers to the term of geocompositions and additionally to term of SCAMIN and SCAMAX attributes, whereas a wealth of content and availability of the data may be combined with each element of a new scheme. So the process of generalization for mobile navigation systems can be considered at several levels.

Figure 1 presents a general scheme of the generalization process of geodata, in the fourth step of which, there is a specification of the simplification of line and polygon features. The previously described selection of objects adjusted to the map details, *i.e.* the use of partial geocompositions, increases the effectiveness of the cartographic presentation. However, this is not sufficient for layers on maps at smaller

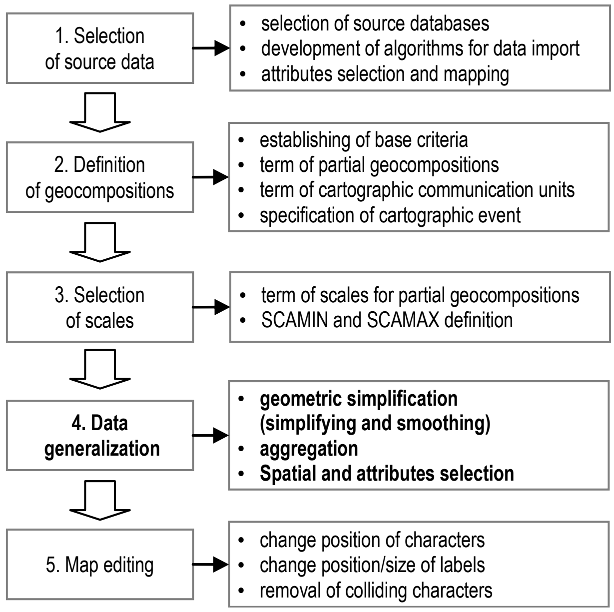

Figure 1. Scheme of the geodata generalization process in the MOBINAV system

scales, the source data of which are very precise, *e.g.* a water layer. Algorithms were used for smoothing and simplifying shapes of objects depending on the resulting map scale. During this research, there were algorithms readily available for implementation in the used software.

During the simplification of line features, the Douglasa-Peucker algorithm was mainly implemented. It is a global algorithm which means that it considers all line points during the points elimination, eliminating only that which are within the accepted tolerance zone (Bielecka, 2006). During the simplification of polygon features, a simplification method which maintained the basic shape and size of polygon objects was used. It takes advantage of the tolerance parameter of simplification and the parameter determining the minimal area of a particular feature. Additionally a tool for smoothing the shape and size of buildings was used, as well as the tool for smoothing using the PEAK method (Polynomial Approximation with Exponential Kernel), *i.e.* smoothing of lines utilising a quadratic function and weighted average for coordinates of all input points at the length of so called "mobile segment", corresponding to the smoothing tolerance. The smaller the smoothing tolerance is, the more details are maintained and longer the necessary execution time becomes. Each smoothed line can have more vertices than the source line (ESRI, 2015). Additionally, the method of combining features located within a particular distance was used. Further still, a tool for selection according to attributes indicating objects which could be removed due to having minor importance for navigation was employed.

Examples of simplification algorithms and the results

Considering the requirements of a future system user, for each system layer, an individual model of simplification was built, including a combination of the abovementioned methods. All studies were realized in the ESRI tool environment using the ArcGIS platform and ArcMap application. The most significant factor of consideration during the simplification was the value of the limitation of the sharpness of human eyes, which has been revealed to be at least 0.2 mm or less at the length of 30 cm from an eye (Chrobak et al., 2007). The assumed terminal values have an influence on a visual perception of a map and significantly increase the efficiency of the media content. Below, examples of two of twenty four developed algorithms, which contain all of the previously discussed components, will be presented. The presented classes have a significant importance for future users of inland waterways, which the system will utilize in order to be of use in tourism and recreation activities. All simplification models were studied in the test area presented in Figure 2, which covers a part of Dąbie Lake along with the marina, a part of the Szczecin-Świnoujście port and a part of Odra Wschodnia River.

During works on the system construction, it was decided to develop a new model of spatial data called MODEF (*MObinav Data Exchange Format*), which was discussed in detail in (Włodarczyk-Sielicka, Kazimierski & Marek, 2014) and (Zaniewicz, Kazimierski & Włodarczyk-Sielicka, 2014). In the case of data presenting bridges of linear geometry and having the BRIDGL acronym, the main source was the BDOT10k database, a Database of Topographic Objects which contains information and data about topographic objects appropriate to maps at the 1:10 000 scale. Apart from attributes of general abstract class, *i.e.*:

- OBJ_ID – unique object ID;
- OBJGEO – type of geometry;
- OBJNAM – object name;
- SOURCE – type of data source (1: ENC, 2: BDOT, 3: OSM, 4: V_map, 5: POI, 6: other);
- SCAMIN – minimum scale;
- SCAMAX – maximum scale;
- the class has additional attributes:
- CATBRG – bridge category (fixed, mobile, hanging, viaduct, other);
- BRGCLR – clearance under the bridge (value in meters).

Figure 3 presents the created simplification model for the BRIDGL layer.

The simplification was prepared for scales 1:10 000, 1:17 500, 1:25 000, 1:50 000, 1:100 000 and 1:250 000. For larger scales, the characteristics of source data was used, while for smaller scales, data after simplification for the scale equal to 1:250 000 was used. For the scale equal to 1:10 000, the Douglasa-Peucker algorithm was used, using a tolerance zone of 2 meters (in accordance to the limitation of the sharpness of human eyes of 0.2 mm). For the 1:17 500 and 1:25 000 scales, the Douglasa-Peucker algorithm with tolerance zones of 3.5 and 5 meters were used, respectively, and all bridges for which the CATBRG attribute had the value of "inne" ("other") were removed. During the simplification of bridges for scales of 1:50 000, 1:100 000 and 1:250 000, apart from the Douglasa-Peucker algorithm (tolerance zones of 10 m, 20 m and 50 m, respectively)

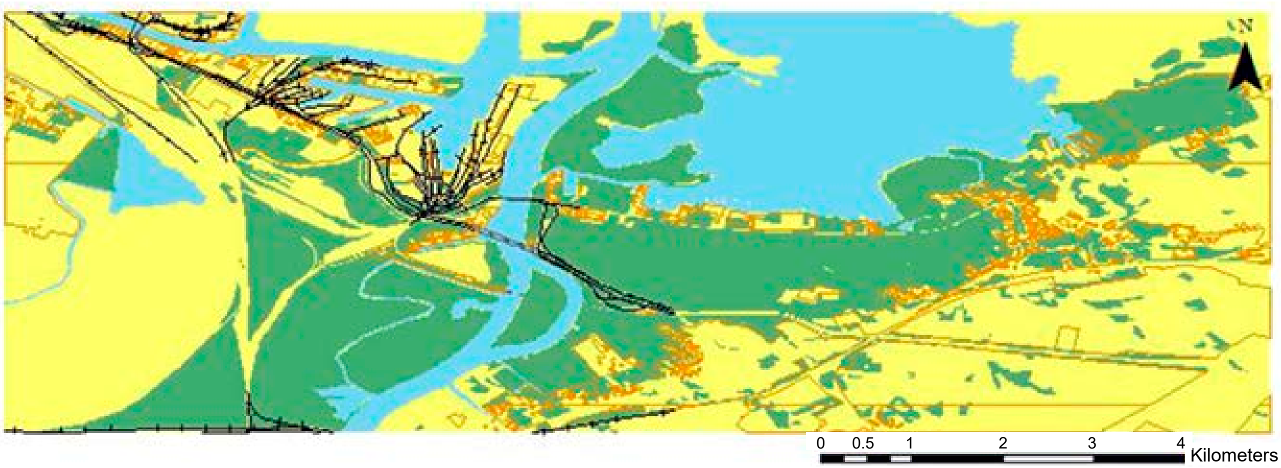

Figure 2. Test area

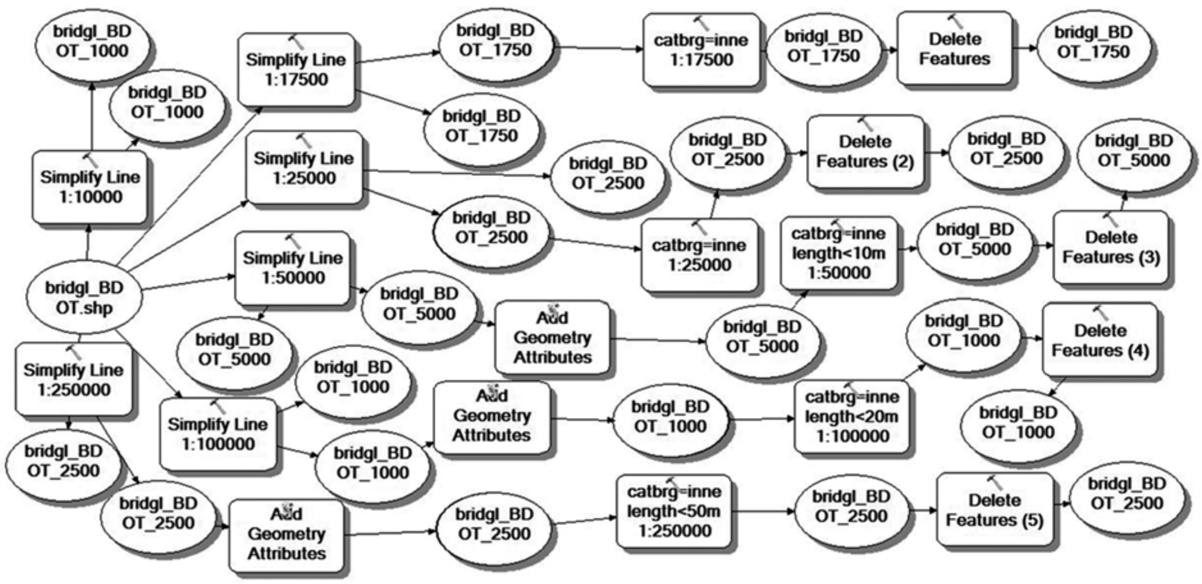

Figure 3. The simplification model for the BRIDGL layer

and the reduction of objects of the "other" category, the features with a length smaller than the assumed one were removed. Figure 4 presents the obtained results for the BRIDGL class.

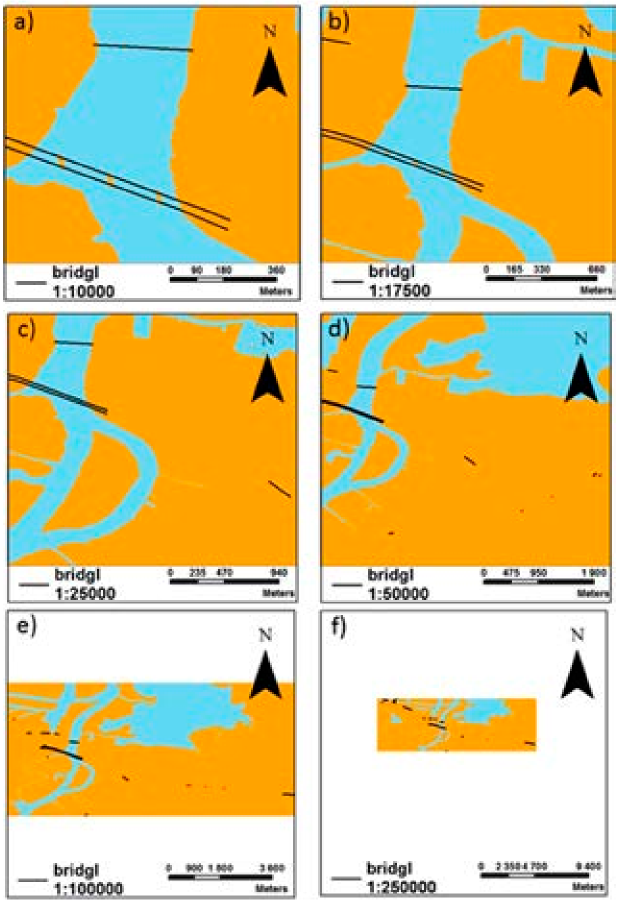

Figure 4. The results for the BRIDGL class of scales a) 1:10 000, b) 1:17 500, c) 1:25 000, d) 1:50 000, e) 1:100 000, f) 1:250 000

The number of vertices of the simplified features of the BRRIDGL class is as follows for particular scales: 1:10 000 – 309; 1:17 500 – 130; 1:25 000 – 125; 1:50 000 – 110; 1:100 000 – 87; 1:250 000 – 67. Observing these values, one must consider that the use of eliminating minor bridges was significant in the built model.

The class called WATERA was selected as an example of the polygon geometry class, which depicts the area of water in an inland navigation system. Not considering attributes of the general abstract class of the MODEF data model, the WATERA class has supplementary attributes:

- CATWAT – category of water area (canal, river, sea, lake, others);
- OPSTAT – operating status (navigable, non-navigable);
- SILZON – zone of silence (yes, no), where a zone of silence indicates an area in which the use of engines is prohibited.

The main data source in the MOBINAV system for the water class is the digitally standardized navigation map IENC (*Inland Electronic Navigational Chart*). The simplification model for water areas was prepared using spatial data of 1:7500, 1:10 000, 1:17 500, 1:25 000, 1:50 000, 1:100 000, 1:250 000, 1:500 000 and 1:1 000 000 scales. For larger scales, the characteristics of source objects were used. Figure 5 presents the simplification model for the polygon layer of WATERA.

During the simplification of the WATERA features for the 1:7500, 1:10 000, 1:17 500 and 1:25 000 scales, a simplifying algorithm for buildings was used to maintain and enforce the orthogonal character of

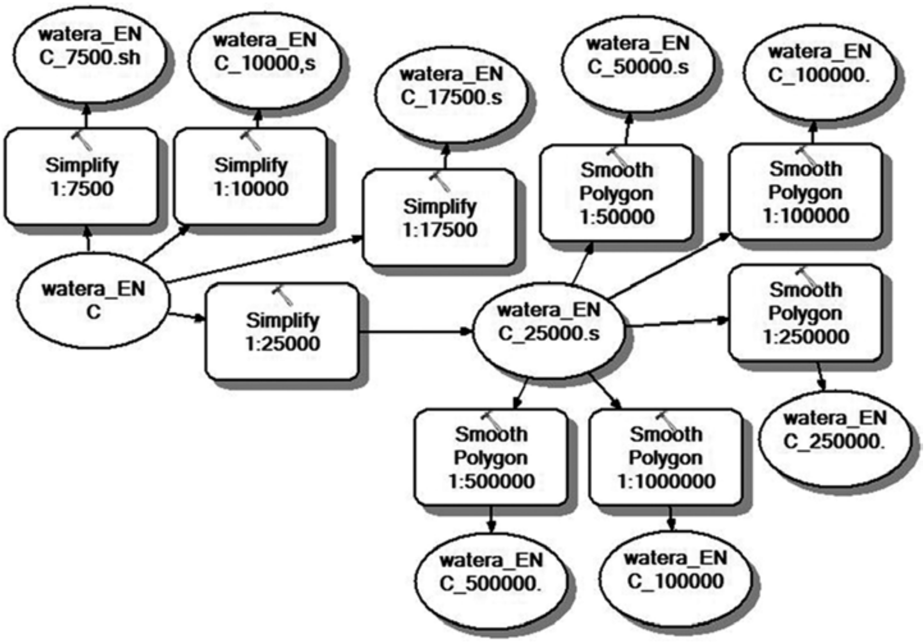

Figure 5. The simplification model for the WATERA layer

the objects' shapes, which is essential in the case of areas such as docks or the port basin. A parameter of simplification tolerance was used (1.5 m, 2 m, 3.5 m, and 5 m, for these scales, respectively) and the parameter specifying the minimal area of a particular feature (2.25 m, 4 m, 12.25 m, 25 m, respectively). In the case of other scales, as with the input data for simplifying algorithms, the class obtained for the 1:25 000 scale was used. A smoothing algorithm using the PEAK method was used with the following smoothing tolerances:

- 10 m for 1:50 000 scale;
- 20 m for 1:100 000 scale;
- 50 m for 1:250 000 scale;
- 100 m for 1:500 000 scale;
- 200 m for 1:1 000 000 scale.

Figure 6 shows the results for water areas obtained using the developed simplification model. The visualization of results for scales 1:250 000, 1:500 000 and 1:1 000 000 was excluded in this work, due to a lack of recognisability of lines in the pictures of the graphical presentations, resulting from the test area being too small.

The number of vertices of the simplified features in the WATERA class is as follows for the particular scales: 1:7500 – 8266; 1:10 000 – 6655; 1:17 500 – 3978; 1:25 000 – 2891; 1:50 000 – 25 004; 1:100 000 – 27 758; 1:250 000 – 17 378; 1:500 000 – 10 849; 1:1 000 000 – 6572. It should be noted that for the 1:50 000 scale and smaller, the number of vertices increases. This is caused by the use the smoothing algorithm (PEAK method). In the model currently under development, the authors have focused on the effectiveness of the cartographic presentation.

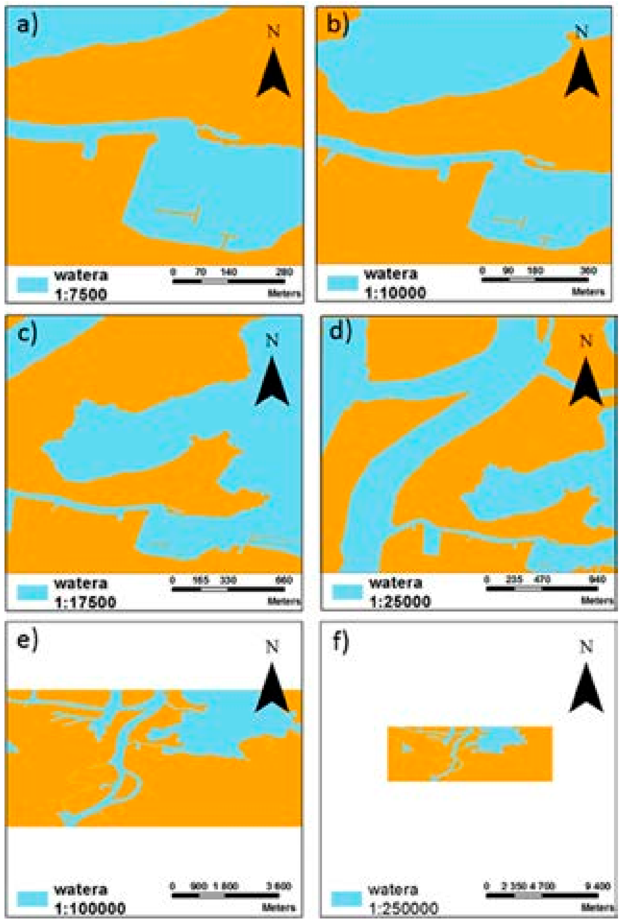

Figure 6. The results for the WATERA class for scales a) 1:7500, b) 1:10 000, c) 1:17 500, d) 1:25 000, e) 1:50 000, f) 1:100 000

Conclusions

The basic aim of a map as an informational tool is to provide a user with knowledge about the surrounding area. Another essential issue is the efficiency of the cartographic presentation, strictly related with the term of spatial data generalization. Another factor apart from the proper selection of source data which has an influence on the map efficiency is the uniqueness of the visualization as displayed on mobile devices. This article concerns the issues of simplifying spatial data in the mobile navigation MOBINAV application, focused on the needs of users of inland waterways, to ensure that the map is correctly interpreted at each scale while avoiding "littering" of the small screen with excess information. The approach presented in the model characteristics included in the geocompositions along with their partial compositions, as well as specification of the values of attributes of SCAMIN and SCAMAX, proved to be a solution of only local character, which can be used only in the case of some object classes. Spatial data of linear and polygon geometry must undergo additional classical generalization methods. In the described process, for each of the system layers, a separate generalization model was constructed, including smoothing and simplification of features' shapes, aggregation of objects and the attribute and spatial selection with elimination of particular objects at certain scales. The main factor considered during the simplification was the value of the limitation of the sharpness of the human eye, related with the term of clearness of map content and requirements of a future system user. The use of a combination of generalization algorithms for spatial data included in the geodatabase of a developed system had a significant influence on the map's lucidity, which is directly related with the efficiency of the cartographic message.

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