BIO Web of Conferences **173**, 03025 (2025) https://doi.org/10.1051/bioconf/202517303025
AFE-2024

Process of cartographic generalization in maps digitalization

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Abstract. This article examines the results of a comparison of two methods of cartographic generalization when creating maps using the traditional method, i.e. “manually” and utilizing automated generalization techniques during computer-based map creation. Generalization is an essential characteristic of any map. Even the most detailed large-scale maps involve a degree of generalization, as representing every object with complete precision is impractical. This text explores the concept of automated cartographic generalization, highlighting its benefits and limitations, as well as the capabilities of computer technologies and specific software in the map-making process. Cartographic generalization creates certain accents and helps to show qualitatively new information on the map. Map compilation is the production of the original map, which involves creating a mathematical framework, incorporating content derived from cartographic materials with appropriate generalization, and finalizing the cartographic representation. The initial map compiler refers to the original map developed through this compilation process, on which the content elements are applied in accordance with the requirements of the editorial documents.

1 Introduction

The depiction and study of natural and social phenomena using cartographic representations have experienced significant evolution, primarily due to advancements in computer technologies, especially in mapping techniques [1, 2]. Cartographic generalization is the process of refining and simplifying map elements to highlight their essential features and unique attributes [3].

While modern map-making tools have advanced considerably, the foundational principles of generalization remain aligned with those of conventional cartography, which historically relied on manual methods. In modern cartography, automated generalization has emerged as a vital component in the creation of digital topographic maps, becoming a cornerstone of the entire mapping process. One of the main scientific and technical directions at present is the development and improvement of automated generalization technology [4-7].

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In recent years, automated generalization has been intensively introduced into the process of mapping. With the development of computer technologies and programs in the digitalization of maps, special attention has been paid to the use of automation of cartographic generalization, although this process is associated with certain difficulties in mapping [8-10].

The purpose of the article is to show the application of automated generalization and generalization by the traditional method, i.e. "manually", in mapping. Of course, it is completely impossible to replace the generalization process with automatic. This is especially true for the factor of the geographical feature of the mapped area. In order to display the characteristic features of the area, preserving the feature of this area, it is very difficult to perform automatic generalization.

2 Materials and research methods

Generalization technology in mapping is is employed to convert a map from its original scale to one with a smaller, derived scale. The factors influencing the extent and nature of generalization include [3, 11]:

- The map's purpose;
- Its scale;
- Geographical characteristics of the mapped region;
- Symbol representation;
- Available cartographic resources.

The process of map transformation during digitalization involves several stages, including preparing a nomenclature sheet for the derived scale map, recoding map elements, generalizing reference points, simplifying hydrography and hydraulic structures, generalizing residential areas, simplifying terrain features, generalizing objects of minimal length or area, and merging with adjacent map sheets [12].

The preparation of the nomenclature sheet for the derived scale map in the program is performed automatically, then you need to complete the task in an automated generalization process.

The automated generalization process plays a crucial role in preserving key information while reducing data volume. For example, when the number of points on a line is decreased, careful selection of the remaining points is necessary to ensure the line's visual integrity remains intact.

In the initial stages of this process, objects are simplified and combined (merged). The final stage focuses on summarizing qualitative and quantitative attributes and introducing new categories of objects, as illustrated in Figure 1.

Simplifying qualitative attributes involves reducing the complexity of object classifications, reorganizing elements in the legend, and respecting the hierarchical structure of geographic data. This is accomplished through classification techniques that use one or multiple predefined parameters.

For quantitative attributes, generalization includes increasing the number of gradations for the phenomenon being represented, transitioning to larger scales, shifting from continuous to stepped representations, or applying uneven scaling. The simplest approach automates the selection and grouping of features and phenomena depicted on the map.

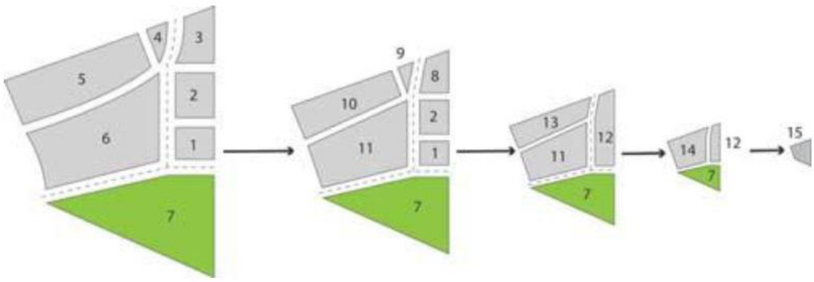


Fig. 1. Stages of generalization and simplification of objects during generalization of digital maps.

In GIS, a map, unlike its paper version, can be visualized at different scales. However, when the scale is reduced, the problem of map overload arises. For generalization in GIS, the so-called scale effect is used. The essence of this method is that the map scale ranges are set for the layer, within which the layer is visible, but when going beyond this range, the objects of this layer are not visualized. But the task of generalization with the scale effect can be solved only partially.

Generalization problems in GIS can be solved in the form of separate operations:

1. Removing small objects You can remove objects, areas or linear objects whose dimensions are smaller than the dimensions of the specified values.
2. Simplification of objects. It is possible to simplify the shape of linear and area objects, due to coinciding nodal points or lying on the same line, but it is necessary set the maximum distance between points or the maximum deviation from the straight line connecting adjacent points (Figure 2).

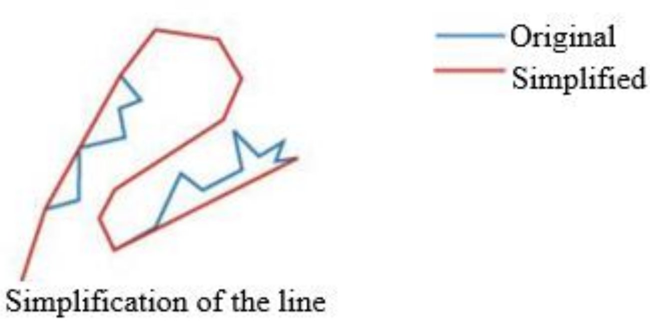


Fig. 2. Simplification of linear and area objects during generalization of digital maps.

3. Smoothing objects. You can smooth the shapes of area and linear objects (Figure 3).

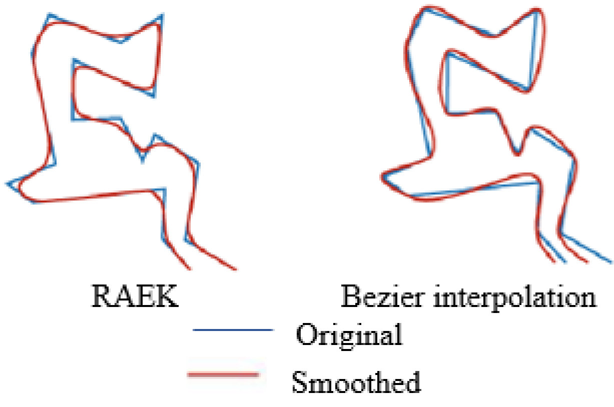


Fig. 3. Smoothing of linear and area objects in generalization of digital maps.

4. Combining closely located area objects. It is possible to combine area objects, the distance between which is less than a specified value (Figure 4).

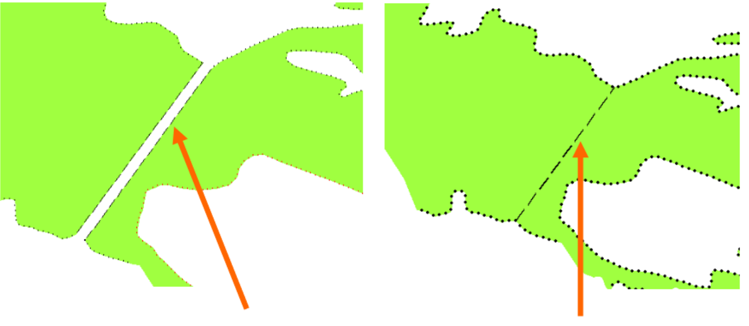


Fig. 4. Combining closely located area objects in digital map generalization.

5. Outlining groups of objects. You can replace a group of closely located objects with one area object.
6. Under reduced map scales, shifting objects involves adjusting their positions to prevent overlap or merging. This process often relies on algorithms tailored for vector formats, which can operate interactively, enabling cartographers to define initial movement directions. In some cases, a smaller-scale version of the object is used to guide the repositioning process and ensure spatial clarity (Figure 5).

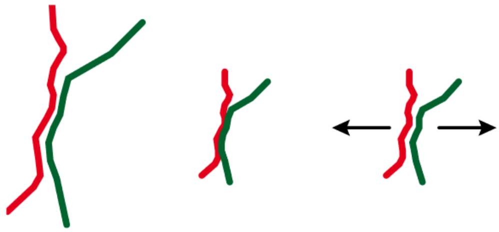


Fig. 5. Adjustment of two linear features to prevent overlap or merging during the digital map generalization process.

7. Exaggeration involves adding specific details back into a simplified dataset to improve its visual representation. For example, when a smoothed line loses its resemblance to features like a coastline, exaggeration can be applied at strategic points to restore its characteristic appearance. This can be achieved by introducing additional points along the line, enhancing its similarity to the original form (Figure 6).

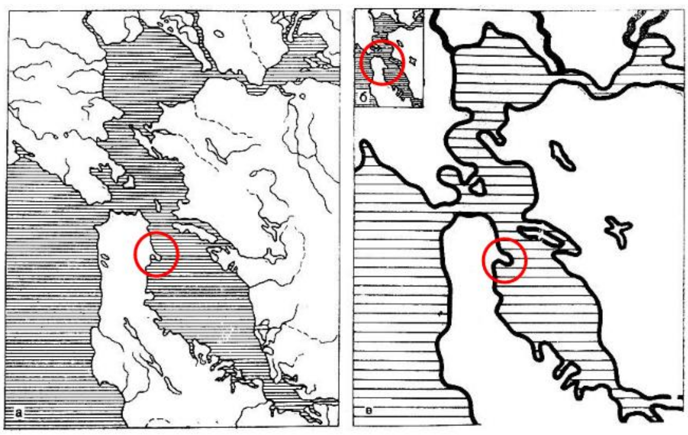


Fig. 6. Exaggeration of an object to improve its visibility when generalizing digital maps.

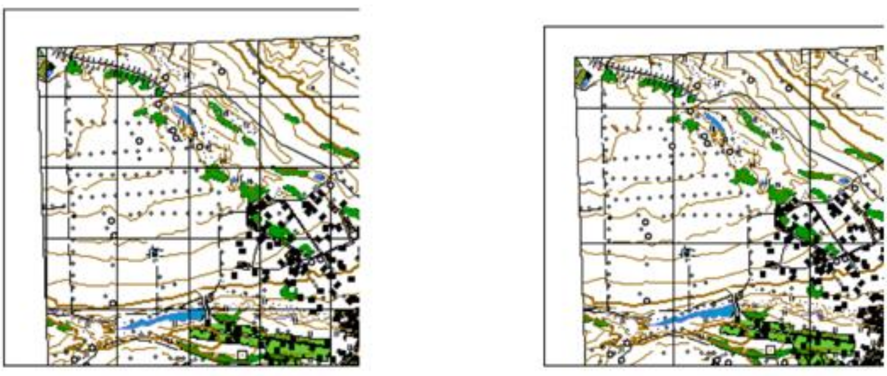
8. Dimensionality reduction. This operation replaces area objects that have an area smaller than a given one with point objects.

For digital topographic maps, the process involves combining four sheets of the original scale to automatically generate a single sheet at the corresponding derived scale. The scaling follows these patterns:

Four sheets at a 1:25,000 scale produce one sheet at a 1:50,000 scale;
Four sheets at a 1:50,000 scale produce one sheet at a 1:100,000 scale;
Four sheets at a 1:100,000 scale produce one sheet at a 1:200,000 scale.

3 Research results and discussion

Carrying out such a process in traditional cartography involves large material costs, a large number of labor resources, and photo lab facilities. It is necessary to first perform a reduction on a KLIMSH photo reproduction Using a camera, negatives of four map sheets are created, which are then mounted onto a single base at the required scale. From this base, an original is produced on paper or plastic, enabling the map compilation process to begin. However, with the introduction of computer-based map digitization programs, the need for photolab processes is eliminated when forming and stitching nomenclature sheets at a derived scale. In this digital approach, a sheet frame and auxiliary lines (both vertical and horizontal) are added to the derived scale map sheet: Vertical lines align with the adjoining vertical edges of the original scale map sheet frames. Horizontal lines align with the adjoining horizontal edges of the original scale map sheet frames. The stitching of map features is then completed along these auxiliary lines (Figure 7). [6, 13].



a b

Fig. 7. Horizontal and vertical coordinate lines of a rectangular grid: (a) represents the grid corresponding to a map at a 1:50,000 scale, while (b) illustrates the coordinate lines of the rectangular grid resulting from the mathematical framework of a map at a 1:100,000 scale.

The stitching of sheets and the formation of a mathematical basis is currently performed on a computer, and it is possible to reproduce the stitching of sheets and the mathematical basis of the map being created on the monitor.

The process of automated generalization is tailored to groups of objects with shared semantic attributes and localization types within a given classification layer. At the same time, adjustments are made to align the metrics of these objects with those in other layers to ensure consistency across the dataset. Objects that define the contour components of the CTC and relief features are generalized separately. In the case of hydrographic and hydraulic structures, sections of area features that fall below a specified width threshold (measured in millimeters on the map) are automatically transformed into linear features for better representation (Figure 8). The conversion from area objects to linear objects is based on a predefined conversion table. The processing of each area hydrographic object involves the following steps:

- Identifying linear objects (e.g., tributaries) connected to the area object under consideration;
- Replacing sections of area objects with corresponding sections of linear objects;
- Extending objects of the Tributaries type to the metrics of the obtained linear objects [6].

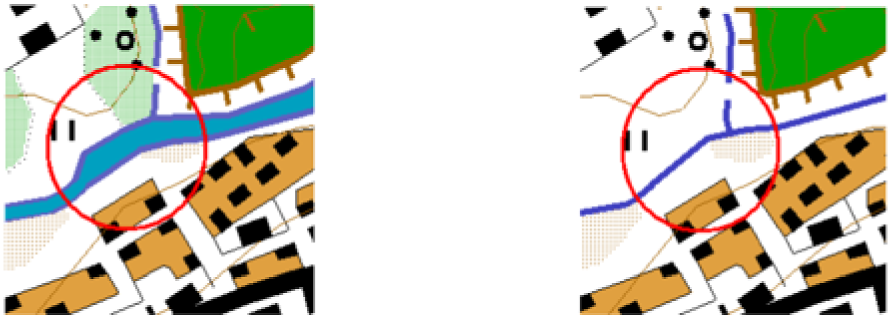


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Fig. 8. Area river and linear tributaries before (a) and after (b) generalization.
During the generalization process, sections of area objects with a width less than the permissible value were automatically replaced with sections of linear objects.

Generalization of relief encompasses the generalization of isolines (such as contour lines, isobaths) and point relief features (Figure 9).

During generalization, isolines (e.g., contour lines) may be removed or transformed into point objects annotated with absolute height values. When contours are deleted, associated elements like bergstriches and labels are also eliminated.

For unclosed contours, their height is evaluated to determine if it is a multiple of the designated height interval of the derived map. If the contour's height is not a multiple of the interval, the contour is removed.

For closed contours, they are assessed to determine if they represent a local extremum. If the contour is not a local extremum, it is treated as an unclosed contour and processed accordingly. If the contour is identified as a local extremum, its area is checked. If the area of the contour is greater than the threshold, the contour is not deleted. If the area of the contour is less than the threshold, the contour (local extremum) is deleted and a point object with absolute height is created instead [6].

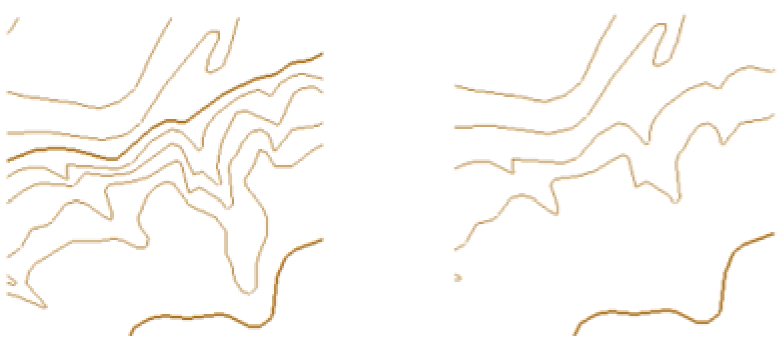

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Fig. 9. Contours with a section height of 10 meters before generalization (a) and after automatic selection of isolines taking into account a section height of 20 meters (b). The isolines are partially removed. On large-scale topographic maps, relief is shown with a section of 2, 5 or 10 meters, on small-scale maps – 20, 50, 100 meters and more.

Generalization of residential blocks begins with the unification of small blocks, as well as increasing the width of passages. Processing of blocks is performed in three stages (Figure 10):

- automated formation of passages;
- shifting blocks, removing unnecessary passages;
- automated formation of quarters.

When performing automated formation of passages in accordance with the established passage width (in millimeters on the map), temporary area objects of the Passage type are created between adjacent blocks.

In the interactive mode Move object (Map Editor) the block is shifted from the centerline of the adjacent driveway if the visible parts of the blocks (not covered by driveways) have an area less than the permissible one. If it is not possible to shift the block (intersection with other blocks) in the interactive mode Delete object (Map Editor) the driveway that reduces the block area is deleted [6].

a b c

Fig. 10. Plan of the blocks of a large settlement before (a) and after (b, c) generalization: a) - the blocks of a large settlement are shown before the formation of passages; b) - the widened passages between blocks are marked in white; c) - the blocks are shown after automatic cutting of blocks by widened passages. In general, small blocks are united , the width of the passages has been increased.

During the generalization of small-sized objects, both linear and areal features on the map are processed, as illustrated in Figures 11-14. The criteria for determining the small dimensions of objects are based on task-specific parameters. For linear features, the minimum length is measured in millimeters on the map to define the threshold for smallness. Similarly, for area features, the minimum area is used to establish the threshold for small objects.

The process involves merging linear features with short lengths by connecting open-ended linear objects that are relatively short. Small area features that are located near each other and belong to the same type are combined into single features. When features are too small to retain their original form, they are converted into point representations.

Unconnected linear features with short lengths and small area features in close proximity are merged based on defined proximity tolerances. For linear objects, this merging occurs when the endpoints of two features fall within the specified maximum stitching distance for linear objects. For area objects, merging is performed when the objects themselves are located within the maximum stitching distance for area objects.

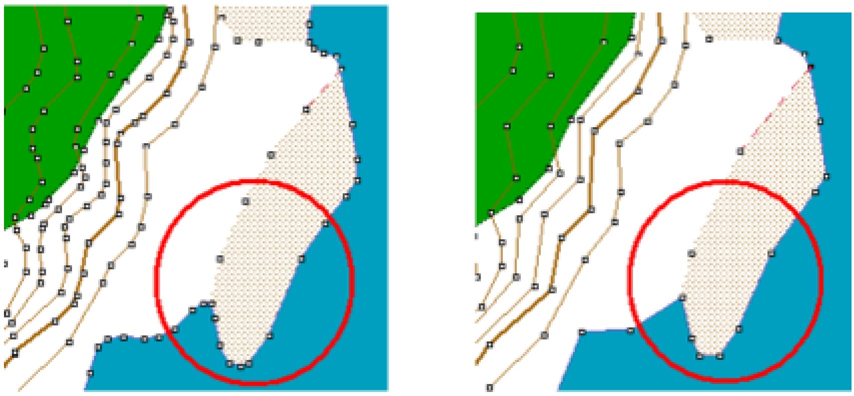

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Fig. 11. Process of smoothing the metric representation of linear and areal objects on the map.

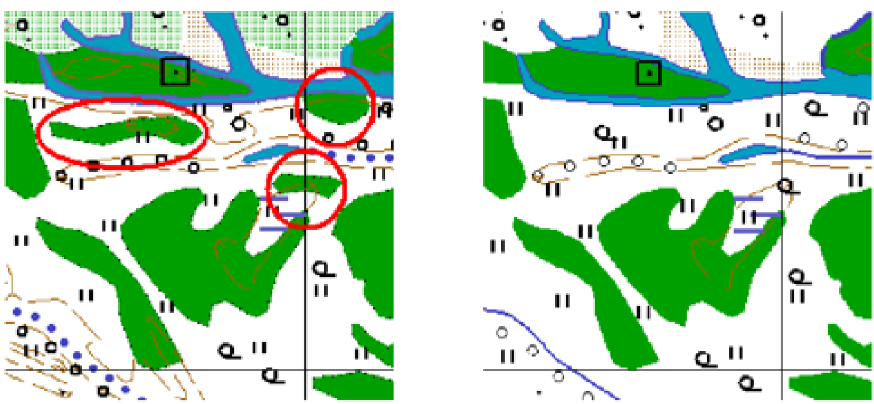

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Fig. 12. Small-area forests before (a) and after generalization of small objects (b). The degree of smallness of the length is determined by the characteristic set in the parameters of the problem.

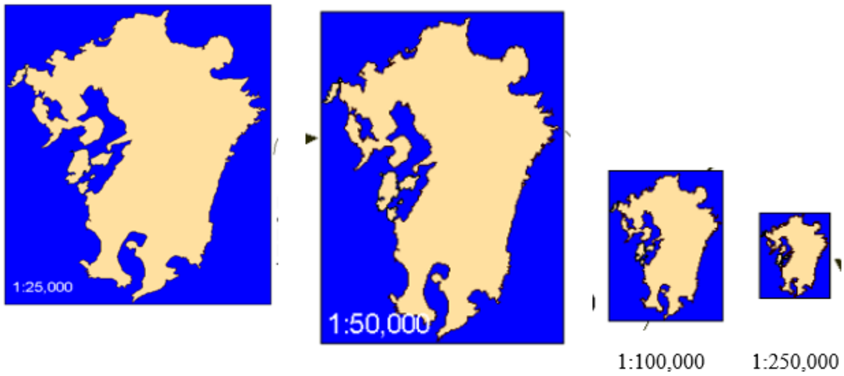

Fig. 13. An example of generalization associated with a reduction in the tortuosity of the island's contours

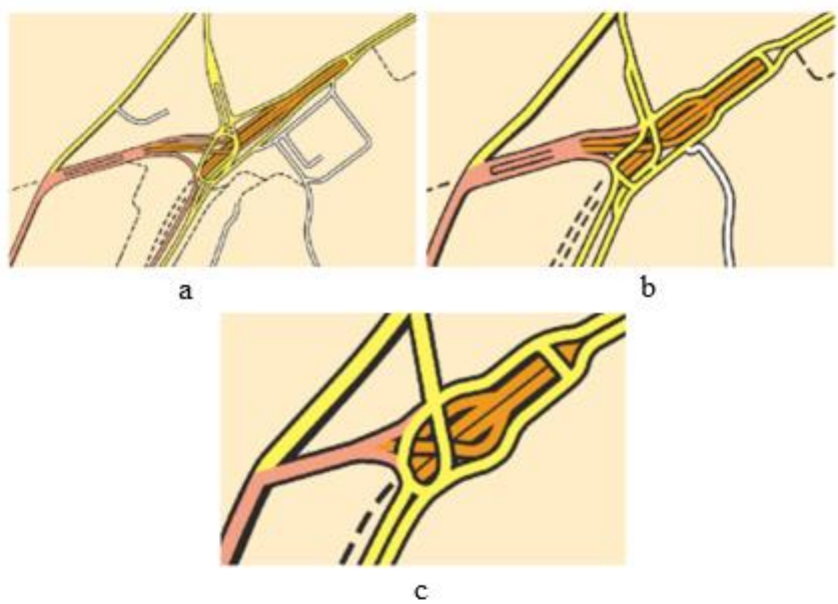

Fig. 14. Road junction depicted at scales of 1:25,000 (a), 1:50,000 (b), 1:100,000 (c).

After completing the process of automatic generalization, it is essential to establish specific tables outlining display standards for each topographic feature across all map and plan scale series. These standards are defined in census tables, which form part of the documentation for mapping technology at each scale. The tables specify numerical thresholds for representing each topographic feature on the map or plan.

To streamline this process, an interface should be developed based on these census tables. This interface would enable users to configure or adjust the formalized rules and thresholds in accordance with editorial guidelines and the unique characteristics of the terrain that shapes the CTC. Additionally, the interface would offer various functionalities to facilitate these adjustments. Firstly, it would enable database management by allowing the addition and editing of descriptive generalization rules and thresholds. This includes the input of numerical census values that are applied "by default" for a specific scale. Secondly, it would allow for the adjustment of default numerical qualification conditions as required by editorial guidelines, considering the terrain characteristics and specific requirements of the CTC. Finally, it would serve as an information and reference system, utilizing the program and its database in tabular format to provide rules and qualifications for automatic generalization. This function would be useful during both the preparatory stages and the monitoring and editing phases of automatic generalization results. Additionally, it would include a search feature to locate the necessary information. both by the number of the conventional sign and by the semantics of the object of the digital technical complex.

The process of cartographic generalization itself is complex and mainly subjective and creative attitude in the creation of topographic maps. And will depend on certain factors when it is necessary to make a derivative scale.

4 Conclusions

When comparing automated and traditional generalization in the preparation of topographic maps, we can conclude that the generalization process is labor-intensive and not everything can be done automatically on a computer. The formation of the nomenclature and mathematical basis of the sheet is performed automatically, bypassing the processes and costs that were in traditional cartography. But when generalizing map elements, difficulties arise, i.e. there are no programs yet that can take into account the geographical features of the mapped area. The selection criteria and standards for cartographic generalization are given in such a way that they cannot take into account the features of the geographical factors of the area. Let's say in sparsely populated areas, any road, even a low-class one, plays an important role in drawing up maps, and the program will make a selection in such a way that it will remove those roads that are important for a sparsely populated area, will not take into account that in such an area any road will be important. It is necessary at the stage of map design when developing editorial instructions to identify the characteristic features of the area for which the map is being drawn up, and taking these features of the area into account and carry out automated generalization. The selection criteria and standards for digitizing the map should be included in the editorial instructions.

Compared to direct digitization or manual generalization, automated generalization significantly enhances labor productivity by reducing both the material costs and the time required to create digital technical documentation for a single production unit. This efficiency is achieved through reliance on industry-specific regulatory frameworks, including manuals, guidelines, symbol libraries, classifiers for topographic and cartographic information, rules for digitally describing objects, and qualification tables for selecting features across scales from 1:500 to 1:200,000.

In traditional cartography, generalization was largely a subjective process, heavily reliant on the skill and experience of individual cartographers. Efforts to formalize this process have incorporated methodologies such as computational geometry, artificial intelligence, and fractal theory. However, despite these advancements, current systems fall short of fully automating core generalization tasks. As a result, cartographers are still unable to entirely shift from manual workflows to fully automated or integrated human-machine approaches. Furthermore, GIS technologies that can comprehensively manage the selection and generalization of cartographic objects while adhering to all generalization requirements remain underdeveloped.

The advent of computer technology and advanced equipment in cartographic production has brought significant progress, but the challenges of achieving efficient and comprehensive automated generalization processes persist.

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